PRODUCTIVITY AND EFFICIENCY OF THE AGRICULTURAL SECTOR: AFRICA WITH A SPECIAL FOCUS ON RICE FARMING AND PROCESSING IN KENYA

By

Eucabeth Bosibori Opande Majiwa

B.Sc. (Horticulture), Jomo Kenyatta University of Agriculture and Technology, Kenya; M.A (Development Studies), National Graduate Institute for Policy Studies, Japan; Diploma (Business Management), Kenya Institute of Management, Kenya

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Queensland University of Technology Business School
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Abstract

Food security remains a serious concern in Africa due to famine, drought and low yields hence food supply is not able to meet increased demand. Limited or uncertain access to food is exacerbated by the degradation of key ecosystems from agricultural and industrial greenhouse gas emissions which are likely to have an impact on future food output. Policy-makers and farmers face the dilemma of how to increase food output while minimising the impact on ecosystems. To tackle the food problem, a better understanding is required of agricultural productivity and the need for environmental improvement. Also needed is the development of strategies to promote staple food crops, given that the global challenge of meeting the food demand can only be achieved through cropping systems which produce important food crops such as maize, wheat and rice. Rice is a particularly key food crop following its recognition as a food security crop during the 1996 World Food Summit.

The thesis comprises two major parts. The first part investigates the performance of African agriculture using a directional distance function to decompose productivity change into technical change, efficiency change and scale efficiency measures. Secondary data from the Food and Agriculture Organization of the United Nations (FAO) statistical database (FAOSTAT) for twenty-seven African countries is utilised for this part of the analysis. The study uses two good outputs (livestock and crop output), three bad outputs (carbon dioxide, methane and nitrous oxide emissions) and five inputs (land, labour, animal stock, capital stock and fertiliser) to measure productivity using the Malmquist index, Malmquist Luenberger and Färe-Primont index. Determinants of productivity (agricultural spending on R&D; average years of schooling; political stability; area of irrigated land; per-capita land and HIV prevalence rates) are examined using data from The World Bank, Agricultural Science and Technology Indicators (ASTI) and other referenced data sources using the Bayesian modelling average technique. The second part of the thesis relies on field survey data of 800 rice farmers and 150 rice millers in Kenya to evaluate the technical, cost and allocative efficiency across the rice agroecological zones using data envelopment analysis (DEA) and fractional regression model techniques. It also examines the two stages of rice processing (milling and drying) using network DEA.

The results indicate that agricultural productivity of African countries has not been impressive. Although the countries have reached high technical efficiency, the small residual scale and mix efficiency values suggest that the countries have failed to produce at the maximum productivity point. Agriculture R&D spending and mean years of schooling had a positive impact on TFP while per-capita land, political instability and HIV prevalence negatively impacted on TFP. In relation to rice farming and processing, the results indicate differentials in the levels of output and input efficiency across the rice zones and the existence of technology gaps. The two-stage rice processing efficiency scores were lower than the conventional scores illustrating the discriminatory power of the two-stage process method. The research addresses policy issues needed to increase agricultural productivity and create a sustainable agricultural environment.

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List of abbreviations

AGRA	-	Alliance for a Green Revolution in Africa
ALDEV	-	African Lands Development
ASDP	-	Agriculture Sector Development Programme
ASTI	-	Agricultural Science and Technology Indicators
BMA	-	Bayesian modelling average
BMS	-	Bayesian model sampling
CABI	-	Centre for Agriculture and Biosciences International
CEPA	-	Centre for Productivity Analysis
CFA	-	Communauté Financière Africaine
CRS	-	Constant returns to scale
DEA	-	Data envelopment analysis
DEAP	-	Data envelopment analysis program
DMU	-	Decision making unit
DPIN	-	Decomposition of productivity index numbers
DRS	-	Decreasing returns to scale
ERP	-	Economic recovery program
EU	-	European Union
GDP	-	Gross domestic product
GHG	-	Greenhouse gases
GHI	-	Global hunger index
FAO	-	Food and Agriculture Organisation
FAOSTAT	-	Food and Agriculture Organisation Statistics
FRA	-	Food Reserve Agency
HIV	-	Human immunodeficiency virus
IFPRI	-	International Food Policy Research Institute

IFAD	-	International Fund for Agricultural Development
IMF	-	International Monetary Fund
IRS	-	Increasing returns to scale
IWUA	-	Irrigation water users' association
LBDA	-	Lake Basin Development Authority
LP	-	Linear Programme
MENA	-	Middle East and North Africa
MI	-	Malmquist index
MLI	-	Malmquist Luenberger index
NCPB	-	National Cereals and Produce Board
TFP	-	Total factor productivity
TFPE	-	Total factor productivity efficiency
OECD	-	Organisation for Economic Co-operation and Development
PIM	-	Participatory irrigation management
PRSP	-	Poverty reduction strategy paper
R&D	-	Research and development
RoK	-	Republic of Kenya
SAP	-	Structural adjustment programme
SRI	-	System of rice intensification
UK	-	United Kingdom
UNCHR	-	United Nations High Commissioner for Refugees.
UNDP	-	United Nations Development Programme
UNEP	-	United Nations Environment Programme
URT	-	United Republic of Tanzania
USA	-	United States of America
USAID	-	United States Agency for International Development
USDA	-	United States Department of Agriculture

WEC	-	World Energy Council
WFP	-	World Food Programme
WFS	-	World Food Summit
WHO	-	World Health Organisation
WTO	-	World Trade Organisation

Statement of original authorship

I confirm that this thesis was finalised during my candidature at Queensland University of Technology, Australia. The thesis acknowledges all existing published material or written works in the text. Further, the thesis does not contain any material which has been accepted for conferment for another tertiary award in my name in any university or other high-level educational institution. In addition, I certify that in future no part of this work will be used in any submission in my name, for any other award (certificate, diploma or degree) in any university or other higher institution of learning without prior approval from Queensland University of Technology's Research Degrees Committee.

Candidate's Signature: QUT Verified Signature

Eucabeth Bosibori Opande Majiwa

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Chapter 1: Introduction

1.1 INTRODUCTION

The role of the agricultural sector in promoting a sustainable economic development process is generally known (Rezek et al. 2011). In recent years, a consensus seems to have emerged that the agricultural sector forms a central place in the development process of a country. Agriculture is generally considered a catalyst for the overall development of any nation hence its growth is essential for many reasons.

As noted by Hayami and Ruttan (1985), agricultural productivity growth is necessary if the output grows at a rate that keeps up with the escalating demand for food and raw materials that is typically accompanied by urbanisation and industrialisation. Ravallion and Datt (1996) found that agricultural growth benefitted the rural and urban populations more than growth in the industrial sector especially in the case of developing countries where the industrial sector is still not well developed. The same observations are corroborated by Irz et al. (2001) who note that agricultural production had a bigger impact on reducing poverty. The authors found that a one third increase in agricultural yields reduces poverty by a quarter or more.

Thus, improvements in agricultural productivity can hasten the start of industrialisation and hence have a large effect on a country's relative income. A greater understanding of the determinants of agricultural productivity will thus enhance understanding of the development process of those nations that are currently poor (Gollin et.al., 2002). Baiphethi & Jacobs (2009) observe that when the agriculture sector becomes more productive, food production will increase, which would reduce poverty and hunger, reduce food costs for those in urban areas and improve farmer's livelihoods. A productive agricultural sector can also help in achieving environmental sustainability where there is better use of natural resources and reduced pressure on marginal lands.

Assessment of the global agricultural productivity indicates a general slowdown in productivity growth especially in developed countries although significant growth has been experienced by developing countries, with improved performance evident in East Asia, South-East Asia and South Asia (Spielman & Pandya-Lorch, 2010; Briones & Felipe, 2013; Fuglie, 2010). Countries such as Brazil and China have had high agricultural productivity growth due to a strong agricultural research system and macroeconomic stability (Mueller, 2016). While the crop yield per hectare has improved in Asia, it is disputed whether Africa has realised the "potential yield"[1]of most crops and livestock; because the yield production for the key staple crops such as maize, bananas, cassava, beans, yams, rice, wheat, sorghum and millet has remained flat or stagnant in Africa. Sub-Saharan Africa (SSA), West Asia, Oceania, and the Caribbean countries generally lag in agricultural productivity growth due to overreliance on resource led agricultural growth, low investment in agricultural research and extension institutions hence recording stagnant or declining growth (Ray et al., 2012).

Because of low productivity, food security remains a major concern for many countries with nearly one billion people being food insecure worldwide. One-eighth of the world's population lack enough food or adequate nutrition at a time when the global demand for food is predicted to increase by at least sixty percent by 2050 (Misselhorn et al., 2012). The FAO estimates suggest that majority (up to three-quarters) of malnourished people are found in developing nations, with the food crisis becoming especially prevalent in Middle East and African countries. Many countries in Africa and Asia face food insecurity due to recurrent drought, famine and low productivity. Whereas the world population is rapidly increasing, many food insecure countries have not yet been able to meet heightened food demand. The limited or uncertain access to food is made worse by the degrading ecosystems and due to the role of agriculture in increasing greenhouse gas emissions which may influence future food output. Oxfam reports indicate that climate change is reliably estimated to cause a ten percent rise in the number of individuals at risk of food insecurity by 2050. This

[1] Potential yield is defined as the maximum yield that could be reached in a given environment (Evans and Fischer, 1999).

is largely due to low crop output, increased staple food prices, decreased earnings, increased health problems and lower food quality (Oxfam, 2013).

Attaining food security requires adopting measures and good practices that support farmers’ production systems to produce enough food to meet people's dietary requirements and that help curb ecosystem degradation (Munang, 2013). Curbing food insecurity also requires putting a significant emphasis and substantial resources towards increasing food production (Nagothu, 2014; Wei et al., 2009; Farmar-Bowers et al., 2013). For example, the green revolution of Asia saw great investment in agriculture which helped triple cereal grain production between 1960 and 2000 thus curbing food insecurity in many Asian countries (Estudillo & Otsuka, 2010). Thus, attaining food security requires developing strategies to promote staple food crops given the global challenge of meeting the food demand can only be achieved through cropping systems which produce important food crops such as maize, wheat and rice. Of these, rice is a key crop following its recognition as a food security crop during the 1996 World Food Summit. Hence, the importance of understanding agricultural productivity and capacity to create strategies to promote staple crops such as maize, wheat and rice while minimising the impact on ecosystems. Increasing food production can only be achieved through improving agricultural productivity (Pratt & Yu, 2008). Food availability which is a key food security pillar[2] will depend on agricultural production levels and processing efficiency. Thus, Policy-makers in food hungry countries should aim at improving agricultural productivity by turning the root causes of chronic food shortage into priority areas of attention.

Understanding productivity sources is imperative and to measure its growth properly becomes necessary. However, the challenge especially for developing countries in SSA where data on input markets is non-existent is how to elicit the correct diagnosis of source of productivity and develop effective policies that would reduce the lagging productivity gap. It requires understanding the impact of

[2] Per the WHO food security is built on three pillars: availability, access and use. This thesis only explores on ‘availability’, ‘access’ and ‘use’ are beyond the scope of this study.

greenhouse emissions on agricultural productivity since it is likely to impact on future food production. In this study the productivity of African agricultural production is evaluated to enhance greater understanding of this sector. Further, key policy implications that may help improve productivity in this sector are drawn.

Previous research studies on African agricultural productivity include those by Fuglie, 2010; Fulginiti et al. (2004); Nin et al. (2003); Nkamleu (2004); Nkamleu et al. (2008); Thirtle et al. (2003) and Rezek et al. (2011) among others. The country level results of the countries examined vary considerably, some showing productivity growth in several periods while others show productivity regress. The differences are due to time series variations, the nature of the countries examined and the analytical method adopted. None of the existing studies explores the impact of greenhouse gases on productivity.

Evaluating productivity while incorporating good and bad outputs has not been examined in African countries. A sustainable environment is thus a major concern considering that average fertiliser use in Africa is now comparable to that in developed countries. Some African countries have intensive livestock production systems similar in size to those in Europe and North America, hence creating a high level of concern about the effect on water bodies and the environment (Bruinsma, 2003). Africa has overtaken Europe as the third largest agricultural greenhouse gases (GHG) emitter, accounting for 15% of global GHG since the year 2000 (Tubiello et al., 2014). In the absence of empirical evidence, it is difficult for policy-makers to ascertain how the degrading of ecosystems due to bad outputs from agriculture is likely to impact negatively on future food production. It is also difficult to put in place feasible approaches that would help mitigate and help farmers adopt better farming practices. The current study thus aims to measure African agricultural productivity while incorporating bad outputs. The study uses carbon dioxide, nitrogen oxide, and methane to represent bad outputs and crop and livestock output to represent good outputs.

This study becomes important in the wake of the 2015 Paris climate change talks that emphasized on a global shift towards low carbon emissions in the energy, transport, agriculture and forestry systems. Incorporating emissions in the measurement of agricultural performance of African agriculture will thus provide the true productivity measure because it considers how farmers allocate the scarce resources to produce more food while minimising the bad outputs. Many countries are making progress towards cutting down on emissions. Countries such as the US are making efforts to promote 'climate smart agriculture'. In Africa, countries such as Malawi and Zambia are promoting 'climate smart agriculture' through agroforestry and conservation agriculture to promote small-holder productivity agricultural systems. Thus, incorporating bad outputs would provide policy-makers in Africa with useful information for determining appropriate mitigation and adaptation approaches in changing conditions of farming practices and ecosystems. It will also help to answer the questions on whether there are differences in productivity when accounting for bad outputs in African agriculture and whether some countries are more productive when emissions are accounted for. From a review of several studies that use existing productivity indices and models to measure agricultural productivity, the gaps identified in the literature include:

1) Analysis of productivity in Africa including identifying the trends, the sources of growth and its determinants. These issues have not been investigated in-depth - a significant oversight considering their critical economic role.
2) No study has undertaken a comprehensive analysis of productivity which incorporates good and bad outputs in African agriculture.
3) Other important sources of productivity in African agricultural productivity have not been explored, an example being mix efficiency.

The first part of the thesis uses the concept of productivity to evaluate agricultural productivity levels and its determinants in selected African countries. The study extends previous studies by undertaking an in-depth analysis of current productivity trends in African agriculture and its determinants. The study also identifies the policy instruments and events that have impacted on agriculture in the countries studied. The study incorporates both good and bad outputs (greenhouse gases) in estimating productivity. Secondary data from the Food and Agriculture Organization statistical database (FAOSTAT) for twenty-seven African countries is utilised for this part of the analysis. The study uses two good outputs (livestock and crop output), three bad outputs (carbon dioxide, methane and nitrous oxide emissions) and five inputs (land, labour, animal stock, capital stock and fertiliser) to measure productivity using the Malmquist index, Malmquist Luenberger and Färe-Primont productivity index. Determinants of productivity (agricultural spending on R&D, average years of schooling, political stability, area of irrigated land, per-capita land and HIV prevalence rates) are examined using data from The World Bank, Agricultural Science and Technology Indicators (ASTI) and other referenced data sources using the Bayesian modelling average technique.

The second part of the thesis relies on field survey data of 800 rice farmers and 150 rice millers in Kenya to evaluate the technical, cost and allocative efficiency across the rice agroecological zones using data envelopment analysis (DEA) and fractional regression model techniques. The study also examines the two stages of rice processing (milling and drying) using network DEA, a gap that has not been filled by existing studies.

Analysing and interpreting recent trends of African agricultural productivity and rice productivity in Kenya will provide Policy-makers with valuable insights into how to mobilise adequate responses that will improve agricultural productivity. The results will also help Policy-makers to adjust agriculture research agendas appropriately.

1.2 AFRICAN AGRICULTURE IN THE GLOBAL CONTEXT

Agriculture in Africa contributes an average of thirty to forty percent of gross domestic product with sixty-five percent of Africans relying on the sector for their livelihood (Fan et.al., 2009).

'*The State of Food Insecurity in the World 2012 Report*', indicates that African agriculture growth rates have declined, with the number of malnourished people increasing. For example, from 1990-92 and 2010-12, the world's share of the undernourished in Africa increased from seventeen to twenty-seven percent. Between 2011 and 2013 alone, one million hungry people were added from Africa alone. As per the 2015 Global Hunger Index (GHI) report, the world hunger levels remain high, with some countries in Africa and South Asia having a serious and 'alarming' GHI values (Von Grebmer, et al., 2015). The United Nations Environment Programme (UNEP) also reveals that African agriculture is highly vulnerable to environmental change. Crop yields are expected to drop by ten to twenty percent by 2050 due to lower-end temperature rise, while the global price of rice is projected to grow by thirty percent as that of maize possibly doubles (UNEP, 2013).

Although Africa has abundant resources such as large arable land, it remains the world's poorest and most underdeveloped continent, with an estimated 380 million people (close to a third of the total population) surviving on less than one US dollar per day (Chen & Ravallion, 2007; WorldBank, 2013). The African rural people remain net food purchasers due to poor market access because of high poverty levels and periods of high prices (FAO, 2012).

Africa's progress in raising agricultural productivity over the last three decades has been disappointing, with productivity growth being flat for much of the past five decades (Pratt & Yu, 2008). For example, while per capita cereal production in Americas, Europe and Asia has been growing steadily, in Africa it has remained stagnant (see Appendix A). Per hectare output of some African countries considered the breadbasket of Africa had not improved greatly (see Appendix B). Furthermore, cereal import statistics for some African countries reveal an increasing trend over recent years (see Appendix C). Breman et al. (2001) noted that per capita cereal output dropped from 150kg to 130kg for African countries during the last 35 years while it increased from 200 to 250kg in the Asian and Latin American countries during the same period. Thus, agricultural productivity growth remains insufficient to curb the high rural poverty levels adequately, enhance food security, and spur sustainable GDP growth rates in African countries (Dessy et.al., 2006). As observed by Diao, et al. (2007) due to high transport costs within the continent, the cost of food in many African countries remains high despite world food prices falling. To address the food security problem, food production needs to be increased through raising agricultural productivity.

Policy-makers in many African nations have thus drawn up agriculture blueprints outlining priority objectives aimed at improving productivity. For example, Kenya's

Vision 2030, which is a long-term national planning strategy, recognises agriculture as one of the sectors capable of spurring a sustained increase in the country's economic growth by the year 2030 (RoK, 2007). Some of the specific strategies captured in the policy document include: transformation of agricultural institutions to bring about household and private sector-driven agricultural growth; increasing output from crop and livestock farming; initiating new land use policies and expanding the agricultural hectarage through developing irrigation infrastructure. The Republic of Gambia's goal of ensuring food sufficiency and increased export earnings stems from its emphasis on increasing agriculture and natural resource output. Ghana's economic recovery program (ERP) identified agriculture as the sector that could rescue Ghana from financial ruin (Berry, 1995).

Further, the meeting of heads of state and government of the African Union member states and other partners held in August 2013 unanimously declared to end Africa's food hunger crisis by the year 2025 through an ecosystem based approach (EBA). EBA is based on developing resilient food production systems and aiding in adapting to climate change. Unfortunately, these policies are rarely backed by tangible empirical evidence and fail to determine the underlying causes of low output in the agricultural sector. Thus, understanding the sources of productivity becomes imperative and necessary to develop effective policies that would reduce the lagging productivity gap.

1.3 KENYAN AGRICULTURE AND ITS RICE SECTOR

Kenya is in the Eastern Africa region (see the map in Appendix D). The country's agricultural sector contributes approximately 25% of its GDP, employs 70% of the population, provides about 40% of the export earnings, and is the main source of the country's food supply. Most crop and livestock farming activities take place in the Kenyan Highlands, which is one of the most successful agricultural production systems in Africa (Nyariki, 2011).

Kenya is characterised by a rapidly growing population, rapid urbanisation, increasing urban poverty, lack of reliable water supply, low food production and lack of resilience to climate change (Glopolis (2013). Kenya hosts about 593,881 refugees and asylum-seekers, of whom 347,980 are based in the Dadaab Camp, 184,550 in Kakuma Camp and 61,351 scattered in major urban areas (UNCHR, 2016). The refugees are mainly from neighboring countries especially Somalia, Ethiopia, Democratic Republic of Congo, Eritrea, South-Sudan and Burundi. The high refugee numbers worsen the increased demand for food especially rice, hence providing a challenge to raise output in the rice sector.

As per the 2015 GHI (see Appendix E), Kenya's hunger level is rated as 'serious' placing it ahead of countries such as Pakistan and Iraq, despite Kenya ranking as one of the huge and fast growing economies in the Eastern and Central African region. Over ten million Kenyans suffer from chronic food insecurity, and a further 1.8 million children are classified as chronically undernourished. In addition, between two and four million people every year are in dire need of food relief (RoK, 2011). Due to the hunger concern, the right to food access is now articulated in Article 43 (c) of Kenya's constitution which states that "*each individual has the right to be free from hunger and to have adequate food of an acceptable quality*" (RoK, 2010a).

Kenya has a highly developed agricultural sector infrastructure, with advanced horticultural, coffee and tea systems enabling it to be a leading world exporter of tea and cut flowers. Despite the well-developed agriculture infrastructure, many Kenyans remain food-insecure, implying that Kenya has utilised most of its potential to produce high-value exports while neglecting food production.

Kenya remains food insecure due to frequent droughts, increased local food prices occasioned by higher input costs, high international food prices and the displacing of many farmers during the 2007/08 political unrest. Kenya's high poverty levels also imply that most citizens' lack food purchasing power and hence are not able to obtain food (Glopolis, 2013). Furthermore, Kenya relies on food imports to bridge the structural gaps that exist between supply and demand and which has been expanding since the 1990s. Kenya's food security situation is dictated by the country's structural issues and the political developments in the Eastern Africa region. The staple foods in Kenya include Maize, rice, wheat, millet and sorghum. Rice is one important crop that has attained a staple food status in Kenya and become a source of calories for the urban people. In Asia, it is a staple crop for more than 50% of the population, which defines food security in the continent as maintaining stable rice prices in the markets of a country (Timmer, 2010). Rice is ranked 3rd after maize and wheat in order of economic importance among cereals in Kenya (RoK, 2009).

Rice remains a key crop for reducing the number of people facing hunger. This fact was recognised at the 1996 World Food Summit where rice was earmarked as a centrally important food security crop. The rice yields in Africa remain low, although the demand is rapidly increasing due to increased urbanisation, changing dietary requirements and rising incomes (Conteh et al., 2012). The coastal countries such as Kenya with good climate offer great hope of meeting projected rice demand.

Rice farming in Kenya commenced in 1907 after the crop was introduced from Asia. 95% of the rice in Kenya is under paddy irrigated systems, and is found in Mwea, West-Kano, Bunyala and Ahero (See Figure 6.1, 6.2 and 6.3) which is comparable with Asia where up to 90% of the crop is grown under flooding conditions. Only about 5% of the rice in Kenya is grown under rain fed conditions in the Coastal region (Kwale, Kilifi, and Tana River Counties) and Western Kenya (Bunyala and Teso districts). The National Irrigation Board (NIB) of Kenya manages the rice schemes. Kenya's rice yields remain the highest in Africa although the yields remain stagnant globally across 35% of the harvested areas. Kenya has great potential of increasing rice production through increased productivity unlike Asia where this potential is rapidly diminishing (Ray et al., 2013). Kenya's rice varieties include Sindano (local variety), IR1561, Basmati and Bg90-2 (Dalrymple, 1986). Majority of rice millers' enterprises are small-scale and privately-owned. The rice millers are mainly found in Mwea with a few located in Kisumu and Ahero.

Examining the literature on rice farming in Kenya reveals that there is no comphrensive study that examines the technical, cost and allocative efficiency of Kenya's rice farming regions as well as the regional technological gaps. Further, the rice processing efficiency and particularly the environmental efficiency of rice processing within the agri-food system has not been examined. In addition, there is no study evaluating two stages of rice processing, i.e., drying and milling.

The thesis thus analyses Kenya's food production with a special focus on rice which, takes a central position as one of the staple food crops that are imported in significant quantities to meet the nation's demand. The country has good rice infrastructure especially irrigation facilities that have potential for increasing output. As the Kenyan market heavily relies on rice imports, improving technical, cost and allocative efficiency will help the sector enhance its competitive advantage.

Given the importance of rice research, this study on rice farming and processing in Kenya was funded by the Australian Awards Africa.

1.4 CONCEPTUAL FRAMEWORK

Low agricultural productivity in many countries is affected by a range of factors, including market failures due to lack of appropriate or effective institutions, macroeconomic instability, high poverty levels, cash crop dependence, population pressure, socio-economic factors such as HIV-AIDS, adverse weather changes and civil wars. Biophysical characteristics such as weather changes and increased emissions may also affect productivity.

Differences in productivity growth in agricultural production is driven by changes in the production technology, production efficiency changes or due to changes in the product mix. In terms of food demand, price volatility, income changes and social economic characteristics of the household are the key determinants.

Low productivity affects the supply of staple foods such as rice and may be caused by biophysical factors due to weather changes, soil type and climate change. Other factors, especially those of socio-economic in nature which include gender, age, education level of the farmers, poor existing infrastructure such as roads and lack of extension services, may also affect productivity.

On the demand side, food supply is affected by changes in income, population increase and changes in household characteristics, e.g., change in consumer preferences or community attitudes or valuation towards certain foods. The differences in rice supply and yield gap can be attributed to variations in farmers' production technology, differences in efficiency levels and due to post harvest processes.

Low productivity implies low levels of food supply, which in turn leads to food insecurity. Figure 1.1 illustrates the major focus of the thesis, and brings out the relationships between Part I of the thesis which examines productivity of African agriculture, and Part II which investigates rice productivity of Kenya.

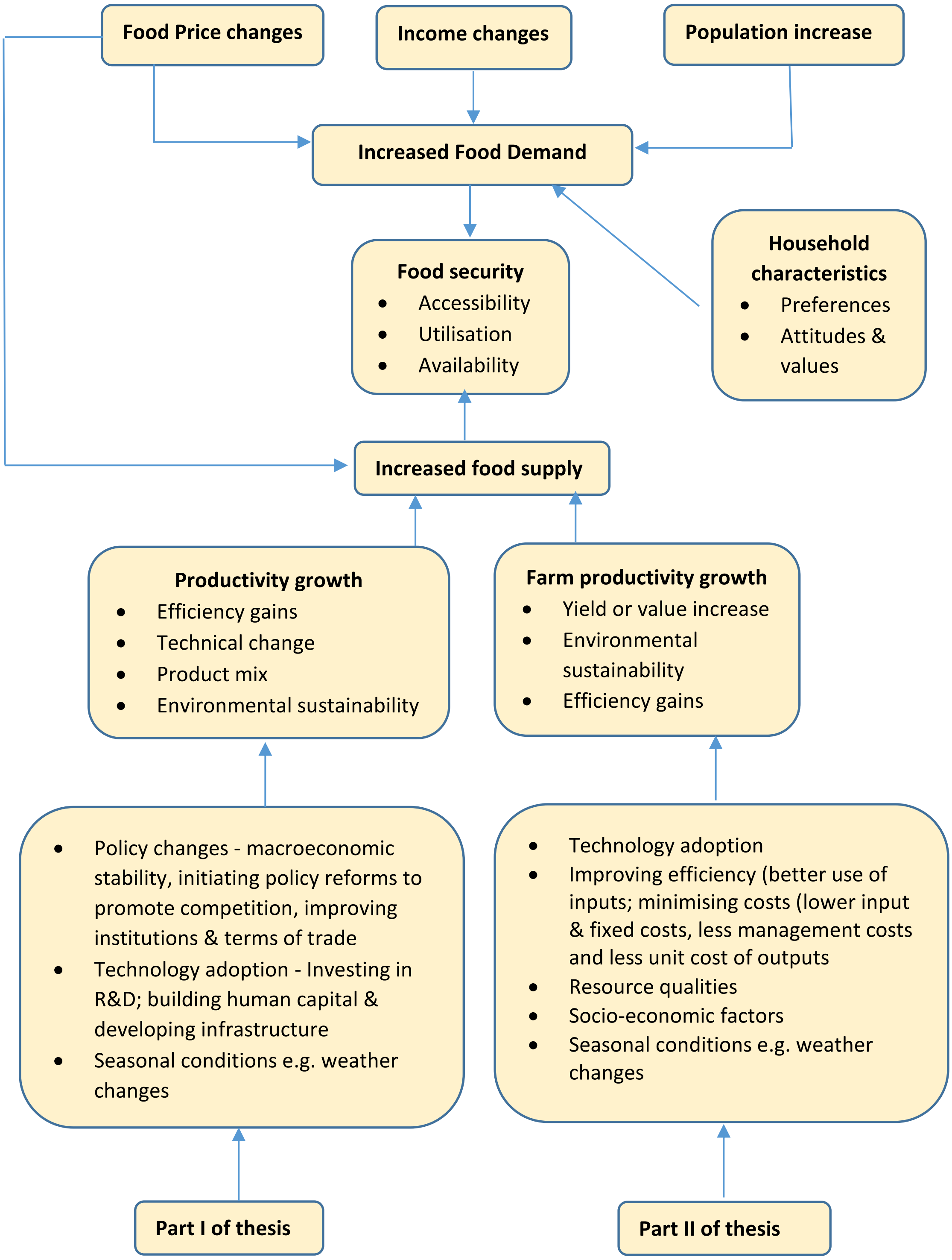

Figure 1.1 Conceptual framework for the thesis

1.5 RESEARCH QUESTIONS AND OBJECTIVES

The main objective of the thesis is to evaluate agricultural productivity in twenty-seven African countries and investigate rice production and processing efficiency of Kenya. For this purpose, the objective of the first part of the study is three-fold. First, the thesis analyses the patterns of agricultural productivity in twenty-seven African countries using the Malmquist productivity index (henceforth MI) and further identifies key policies and events that may have had an impact on productivity. Second, the study investigates productivity by incorporating three bad outputs from land use, i.e., carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) using the Malmquist Luernberger Index (MLI). Third, the study examines sources of productivity that have rarely been discussed in the literature especially in terms of the mix efficiencies by using Färe-Primont productivity index (FPI). Finally, the determinants of productivity are investigated using the Bayesian modelling average technique.

To improve rice productivity in Kenya, the second part of the thesis addresses the following objectives:

1) To investigate the efficiency of rice farming, its determinants and technological gaps across the rice agroecological zones of Kenya.
2) To investigate rice processing efficiency and its determinants in the Mwea region.
3) To study the efficiency of the two stages of rice processing, i.e., milling and drying and their determinants.

The results obtained from the analysis will help answer the following research questions:

1) What is the agricultural productivity change in the selected African countries?
2) What is the productivity change in the selected African countries when agricultural emissions are incorporated in the estimation of agricultural productivity?

3) What are the major determinants of productivity of African agriculture?
4) What are the other components of productivity of African agriculture?
5) What is the average technical, allocative and cost-efficiency of rice farms and mills in Kenya?
6) What are the determinants of rice farming and milling in Kenya?
7) What is the mean technical efficiency score when considering emissions in rice milling?
8) What are the mean efficiency scores when the two stages of rice processing are considered?

1.6 CONTRIBUTIONS OF THE STUDY

Many scholars have identified low agricultural productivity as the major cause of food insecurity in Africa due to the following reasons: high poverty levels, market and information failures, cash crop dependence, poor governance (due to corruption and political instability), rapid population growth, extreme weather changes, HIV-AIDS and civil wars, among other factors. However, the literature provides only an incomplete analysis of the underlying issues of low agricultural productivity and the determinants of productivity especially for African countries. The literature also fails to address the issue of productivity and emissions, and how agricultural productivity growth rates change when incorporating emissions in the production function especially in the context of African agriculture.

The first part of the thesis analyses and provides an explicit comparison of agricultural productivity and its component across twenty-seven African countries using existing productivity models. The study extends existing literature in agricultural and resource economics by measuring productivity while incorporating three bad outputs, i.e., CO_2, CH_4 and N_2O greenhouse gases from agriculture thus estimating environmental adjusted productivity growth for African countries, a gap not filled by the previous studies. The study also investigates the determinants of productivity by using measures that directly affect productivity, including agricultural R&D spending, average years of schooling of farmers, area of irrigated land, per capita land, HIV prevalence and political stability as a measure of governance, and draws policy insights that would bring about agricultural growth in Africa. Again, the study examines other sources of productivity in African agriculture, especially the mix efficiency, a measure not captured by previous studies.

The motivation for the second part of the thesis which focuses on rice farming in Kenya arises from the fact that the literature lacks a comprehensive description of the important linkage between producers and millers, which can indicate whether low rice productivity is due to production or processing inefficiencies. The important issues that exist when examining efficiency of production systems is that most of the studies focus on farm technical efficiency and neglect the post-harvest process. Second, existing studies that gauge the efficiency of post-harvest operations employ standard DEA, which does not accurately capture all the stages or divisions of the production process. Given rice is an important food security crop, the thesis examines the technical, cost and allocative efficiencies of rice farming and rice processing. The study also examines the technology gap ratio within rice-farming areas as well as the two-stage process in rice processing - drying and milling.

At present, there is limited in-depth analysis of agricultural productivity in Africa and particularly, rice productivity in Kenya. In the absence of comprehensive information, both farmers and policy-makers may not be well informed about the magnitude of productivity and efficiency challenges. This research will provide useful insights that will help policy-makers come up with policy directions geared towards addressing productivity gaps and spur agricultural growth. The results will also be critical in helping policy-makers adjust research agenda in agriculture appropriately, and assist farmers reallocate resources away from producing bad outputs to good outputs.

1.6.1 Papers arising from the thesis

The following papers arising from the thesis have been presented in conferences or prepared for submission for publication as follows:

- Majiwa E. B., Lee B., & Wilson C. (2015). Multi-lateral multi-output measurement of productivity: the case of African agriculture. Paper presented at the 29th International Conference of Agricultural Economists, August 8-14, 2015 Milan, Italy. http://ageconsearch.umn.edu/handle/212769.
- Majiwa E. B., Lee B., & Wilson C. (2016). Increasing agricultural productivity while reducing greenhouse gas emissions in Sub-Saharan Africa: myth or reality? (Paper under revision for submission to Journal of Agricultural Economics).
- Majiwa E. B., Lee B., & Wilson C. (2016). A network DEA model of post-harvest production: the case of Kenya's rice processing industry (Paper submitted to Food Policy Journal).

1.7 STRUCTURE OF THE THESIS

The thesis consists of two major parts. The first part investigates agricultural productivity trends of twenty-seven African countries using secondary data from FAO for the period 1980 to 2012. The introduction is outlined in Chapter One. Chapter Two examines productivity related literature. Chapter Three outlines the methodology and the data sources used for the agricultural productivity analysis. Chapter Four presents the results of part one of the thesis.

The second part of the thesis focuses on Kenya and relies on primary data from a field survey data of 835 rice farmers and 150 rice millers to investigate the technical, cost and allocative efficiencies and its determinants. Chapter Five examines the related literature on rice farming and processing. Chapter Six presents the methodology and data source for the rice farming and processing analysis. Chapter Seven provides the rice farming and processing efficiency results.

Chapter Eight outlines the conclusions, policy recommendations, limitations and recommendations for further research.

PART I – MEASURING PRODUCTIVITY OF AFRICAN AGRICULTURE

Chapter 2: Productivity of African agriculture

2.1 INTRODUCTION

This study reviews the agricultural productivity patterns of twenty-seven African countries for the period 1980 to 2012. The chapter first provides background information of the countries in Section 2.2 followed by an outline of the concept of productivity analysis in Section 2.3. Section 2.4 reviews related literature on agricultural productivity followed by a summary and implications in Section 2.5.

2.2 BACKGROUND INFORMATION OF THE COUNTRIES

The African continent has fifty-four fully recognised sovereign states which include Madagascar and other archipelagos, nine territories and two *de facto* independent states (see map at Appendix D). The following regions encompass the 54 African countries; Central Africa (Central African Republic, Congo, Democratic Republic of Congo, Equatorial Guinea, Gabon and São Tomé and Príncipe), North Africa (Egypt, Libya, Tunisia, Algeria, Morocco and Western Sahara), Eastern Africa (Eritrea, Ethiopia, Somalia, Djibouti, Sudan, Uganda, Kenya, Tanzania, Rwanda, Burundi, including the islands Comoros, Mauritius, Seychelles and Madagascar) and Southern Africa (Angola, Botswana, Lesotho, Malawi, Mozambique, Namibia, South Africa, Swaziland, Zambia and Zimbabwe). The countries to the south of the Sahara Desert are often referred to as Sub-Saharan African (SSA).

Geographically and in terms of population, Africa is the second-largest and most populous continent after Asia, with a population of over one billion people, thus accounting for approximately fifteen percent of the world's population. Africa's estimated area of 30.2 million km^2 accounts for about six percent of the world's surface area and 20 percent of the world's land area. Hence, Africa has great potential for expanding its agricultural production (Okigbo, 1982).

African agriculture revolves around small-scale holders who manage about 80 percent of the farmland and who have access to 2 hectares or less per household.

They supply approximately 80 percent of the food consumed in the continent. African farmers grow diverse crops and keep several livestock (see Appendix F and G), and the output from the enterprises accounts for close to two-thirds of Africa's gross agricultural output value. The African continent has more than 600 million and 700 million head of livestock and poultry, respectively (Gabre-Madhin & Haggblade, 2004). The production of cereals and starchy root crops in Africa is of importance, since the crops form a large part (up to two-thirds) of the population's total dietary requirements (Diao et.al., 2012). The individual countries' key economic indicators and other agricultural production indicators are summarised in Table 4.3.

2.3 CONCEPTS OF PRODUCTIVITY AND PRODUCTIVITY CHANGE COMPONENTS

Productivity is defined as a ratio of combined output (e.g., land, capital and materials) - such as aggregate crop or livestock output to aggregate inputs. Productivity changes occur when output grows faster than the rate of input growth. This leads to an improved real or value output growth, which in turn implies greater output from a given possible input sets and outputs (production possibilities set). Productivity changes may also emanate from increased intensification i.e. higher use of inputs that are not related to land such as capital, labour, water or fertiliser or due to price change thus resulting in an increase in value.

The neoclassical and endogenous growth models are the foundation of the concepts of productivity. Both models utilise an aggregate production function to explain the output growth based on the accumulating factor inputs. Since the introduction of the Solow (1957) growth accounting model, many studies have explained economic growth by breaking it down into input growth changes and technical change measures. In the 1970s and 1980s, cross-country studies compared agricultural productivity across countries. Such studies include Hayami & Ruttan (1971); Kalirajan & Shand (1985); Kawagoe & Hayami (1983); Lau & Yotopoulos (1989). Recent developments in agricultural productivity analysis include the works of Barnes (2006); Bates & Block (2013); Belloumi & Matoussi (2009); Coelli & Rao (2005); Färe et al. (2007); Rao & Coelli (2004).

Productivity growth measures the rate of productivity change when compared to the previous years' level. Productivity growth influencing factors include farm size changes, adoption of new of technologies, increased rate of discovery of new technologies, initiation of new policies, changing the way a market operates or making changes in the physical environment (Mallawaarachchi et al., 2009).

Productivity growth is driven by three key factors namely, due to change in production technology, improved efficiency and product mix changes. Technical change occurs when the existing frontier shifts due to changes in the production possibility set. The efficiency gains components comprise of technical, allocative or scale efficiency changes. Technical efficiency increases occur either when inputs are utilised optimally resulting in increased output, or when a lower level of inputs is used to achieve the same output level. When inputs are combined optimally based on their respective prices, then allocative efficiency is achieved, which often coincides with improved input expenditure leading to production of the same quantity of output at a lesser cost. Scale efficiency occurs when the cost of producing an output matches the operating scale. Changes in product mix occur when consumers change or shift their demand to higher-quality output with rising incomes, or when products of high value become more important over time.

Productivity is generally used to make comparisons among industries, countries or years. The United States Department of Agriculture (USDA) identified productivity indices as useful indicators for the following purposes: to ascertain the sources of economic growth; justify the setting apart of research funds; estimate production relationships; to measure technical change; to compare inter-sectorial performance, and to explain price changes in the 1980s. Since then, deriving productivity growth components has become relevant in unveiling the unaccounted-for sources of growth beyond those exhibited in the production process. Thus, productivity is considered as the residual growth component from the microeconomic perspective, which is attributed to technical change, efficiency change, scale efficiency change and to other factors for example socio-economic factors that do not directly affect the production process (Mustapha et al., 2013).

2.4 LITERATURE ON AGRICULTURAL PRODUCTIVITY

This section provides the literature review. Section 2.4.1 provides a global review of agricultural productivity, Section 2.4.2 outlines literature on productivity when 'bad' output in factored in the analysis. Section 2.4.3 provides literature on sources of productivity while Section 2.4.4 provides a summary and implications of the literature review.

2.4.1 Agricultural productivity in the global economy

There exist several studies that have examined productivity within the agriculture sector focusing either on individual countries or multilateral comparisons. Examples of agricultural productivity country-specific studies include using the Tornqvist-Theil approximation of the Divisia Index to measure United Kingdom agriculture for the period 1967 to 1990 (Thirtle & Bottomley, 1992); Southern Africa agriculture (Thirtle et.al., 1993) and Western Australian broad acre agriculture (Coelli, 1996). Chen and Ding (2007) used the MI index to assess China's agriculture infrastructure trends and its impact on productivity based on province level panel dataset for the period 1988 to 2002. Jin et al. (2010) examined China's agricultural sector productivity trends after the program of reforms with an emphasis on the 1990 to 2004 period using a stochastic production frontier. Brigatte and Teixeira (2011) analysed the impacts of variables on GDP and productivity of Brazilian agriculture for the period 1974 to 2005 using the Johansen co-integration method. Kannan (2013) estimated productivity and its determinants of ten major crops grown in the Indian State of Karnataka using the growth accounting method of the Tornqvist-Theil Index; among other studies.

Agricultural productivity multilateral comparisons include that of Bureau et al. (1995) who compared the productivity of the agriculture sectors of nine EU countries and the USA from the year 1973 to 1989 using the Fisher, Hulten and Malmquist non-parametric measures of productivity. The authors found the MI to give consistent estimates with the Fisher and Hulten estimates. Fulginiti and Perrin (1997) used the MI to investigate productivity changes in eighteen developing countries between 1961 and 1985 and concludes that there was a decline in at least half of the countries examined. Arnade (1998) evaluated productivity for seventy countries both in developed and developing economies using the MI index approach and conclude that agriculture in developing countries was technically inefficient with technical change having a greater impact. Coelli and Rao (2005) examined productivity change of ninety-three countries for the years 1980 to 2000 using the MI approach and found on average productivity change among the sample countries was 2.1%. Nin et al. (2003) examined productivity change for twenty developing countries (spread across the world) for the period 1961 to 1994 and found technical change to be the driving force for productivity growth.

Regarding studies comparing African agricultural productivity, results on growth rates are mixed. For example, Nkamleu (2004) measured productivity growth and its components for sixteen African countries over the period 1970 to 2001 and noted that technical efficiency drove productivity growth rate rather than technical change. Fulginiti et al. (2004) measured productivity in forty-one African countries from 1960 to 1999 using a semi-non-parametric Fourier production frontier and found an average productivity change of 0.83% although the annual average rate was 1.9% for the period 1985 to 1999. Nkamleu et al. (2008) evaluated the relationships between productivity growth, input accumulation, institutional and agroecological change using a panel dataset consisting of twenty-six African countries for the period 1970 to 2000. The author found positive productivity change could be attributed to technical progress. Nin et al. (2008) examined productivity trends of ninety-eight countries, of which thirty were African. The results indicated an exceptional improvement in SSA's agricultural growth, especially for the period 1984 to 2003. The growth of 3.2% per annum was attributed to increased output and changes in input composition. Fuglie (2010) examined productivity growth in forty-seven African countries from 1961 to 2006 and found productivity growth rate to be 0.58% per annum on average, with the lowest being -0.18% per year experienced in the 1970s and highest 1.17% per year, achieved in the 1990s. The author found expanding cropland to be the key source of growth rather than improved productivity.

Alene (2010) measured productivity growth for fifty-three African countries by applying the contemporaneous and sequential technology frontiers for the period 1970 to 2004. The author observed that productivity growth rate was 1.8% per year, and found research and development (R&D) expenditure and productivity growth to be positively correlated. Rezek et al. (2011) used DEA, stochastic frontier, Bayesian efficiency and generalised maximum entropy methodologies to assess agricultural productivity growth for thirty-nine African countries over the years 1961 to 2007. The author found that stochastic frontier, generalised maximum entropy, and Bayesian efficiency techniques generated better productivity growth rankings than DEA providing estimates that significantly correlated with outcome measures.

The studies examined reveal that the productivity levels of each country varied depending on the number of countries and span of the data period used, and the nature of the model adopted for the analysis. Alston et al. (2010) also noted this phenomenon and attributed the differences in the results to the quality of data available among countries, the length of time periods used and variation in measures and methods used. The authors noted that even if they confidently concluded that productivity growth had slowed over time, this may not be obvious from the findings, especially when observing a productivity slowdown under either favourable or unfavourable weather during growing seasons. The authors also noted that it was difficult to identify the difference between annual productivity growth over time and the changes between years especially a change that was sporadic in nature (e.g., China and the former Soviet Union's massive institutional reforms). Further, the authors' note that productivity growth appeared to have slowed in developed countries especially the USA, UK, Canada, and Australia for which better quality measures were available while such data were lacking for many other nations. The authors recommended further investigation of agricultural productivity to ascertain its growth.

It is widely accepted that agricultural productivity remains important given, its role in attaining food security. Policies and programs which aim at improving agricultural productivity in Africa are therefore necessary, as is the research that investigates productivity and its determinants. In this way, research will provide empirical evidence for developing appropriate policies and programs. Although Rezek et al. (2011) recently assessed agricultural productivity growth rate in Africa and the outcomes affecting productivity, the authors acknowledge that they used measures which do not directly affect agricultural productivity such as per capita food consumption, food exports, industrial sector as a percentage of GDP, national savings rate and the share of the urban population.

In contrast, this research identifies the significant policy changes and events that have an impact on country-specific productivity, and assesses the determinants of productivity. The proposed determinants of productivity include agriculture R&D spending, average schooling years to represent the education levels of the countries, the area under irrigation to capture the differences in land quality, per capita land as a proxy of land size, HIV prevalence to represent the human health well-being and political stability as a measure of governance. Given that the use of tractors among small-scale farmers in Africa is still very low, the thesis uses the gross capital stock instead as a measure of capital. Furthermore, the number of tractors fail to indicate the range of quality and intensity of use either over time or across countries. The study also removes the seasonality effect on output value by smoothing. The study also sets a basis for comparing productivity when bad environmental outputs are incorporated. The research is designed to provide relevant empirical data which can support policies aimed at increasing agricultural productivity and ensuring that agriculture practices are environmentally sustainable.

2.4.2 Agricultural productivity incorporating bad outputs

Agriculture processes often produce a range of products (food, fibre, bioenergy, medicines, etc.) which are considered good outputs, but, also produce undesired outputs such greenhouse gases, nutrient or soil loss, and other forms of land degradation all with impact on the environment. Statistics indicate that agricultural systems contribute significantly to global GHG, namely, carbon dioxide (CO_2), methane (CH_4), nitrogen oxide (N_2O) and ammonia (NH_3) which promote global warming (see Appendix H). The agricultural sector's GHG account for about 25.5% of global emissions from non-anthropogenic (non-human) sources, and 60% of GHG from anthropogenic (human activities) sources; with livestock husbandry accounting for 18% of these total GHG (Sejian & Naqvi, 2012). Africa's agricultural system currently accounts for 15% of global agriculture GHG and since 2000 Africa has overtaken Europe as the third largest GHG emitter (Tubiello, et al., 2014). Moreover, African agricultural emissions are projected to grow even more rapidly - by about 30% - between 2010 and 2030 (AGRA, 2014).

In a typical production process, bad outputs such as GHG and good outputs such as food are often produced together. The possibility of jointly producing good and bad outputs is often overlooked in the conventional measure of productivity since it is difficult to assign market "prices" for undesirable (bad) outputs (Chung et al., 1997). As Chung et al. (1997) note that good outputs are marketable products whose prices are known, whereas the bad outputs are difficult to price in a conventional way. Developed countries' disposal of bad outputs is often regulated by public authorities, and many developing countries are yet to consider the effect of these bad outputs (Picazo-Tadeo et al., 2005; Mertz et al., 2009).

Studies incorporating bad outputs in productivity measures have focused on developed countries' context in manufacturing, transport and energy sectors. Chung, et al. (1997) investigated productivity changes in thirty-nine Swedish pulp and paper firms for the period 1986 to 1990. The bad outputs included biological oxygen demand, chemical oxygen demand and suspended solids. The results indicated that productivity improved over the examined period, with the source of growth being technology advancement rather than improved efficiency. Yörük and Zaim (2005) employed both MI and MLI to measure productivity growth in twenty-eight OECD countries for the period 1983 to 1998. They considered nitrogen oxide and organic water pollutant emissions as bad outputs and found that the ML indices recorded higher productivity estimates compared with the conventional MI for the OECD countries.

Kumar (2006) used the MLI to analyse productivity change in forty-one countries for the years 1971 to 1992, and compared the results with the conventional productivity measure. The author found no difference in the productivity index values when accounting for CO_2 emissions even though the technical change and efficiency change had different values. Yu et al. (2008) measured productivity growth for four Taiwanese airports for the years 1995 to 1999 and found that the average productivity growth was as high as 8.0% over the period, with growth biased upward when bad outputs reduction was ignored. Pathomsiri et al. (2008) assessed the productivity of fifty-six US airports during the period 2000 to 2003 and modelled both good and bad outputs (delayed flights). The results revealed that when delayed flights were ignored in the model, the big but crowded airports exhibited higher efficiency scores than their small but less congested ones. However, accounting for delays, the small and less crowded airports were identified as efficient.

Kumar and Managi (2010) proposed a productivity index that captures bad outputs such as CO_2 and SO_2 and measured productivity of fifty-one countries from the year 1971 to 2000. They found that half of the countries exhibited productivity growth. Oh and Heshmati (2010) employed a sequential MLI to measure the environmentally adjusted productivity growth for twenty-six OECD countries between 1970 and 2003 and compared the results with the conventional measure. The authors found efficiency change to be the driving force in the conventional productivity measure while technical change influenced the environmentally adjusted productivity growth. However, the average productivity growth between the two models was not found different. Zhou et al. (2010) introduced a Malmquist CO_2 Performance Index (MCPI) to measure total factor carbon emission performance in eighteen of the world's top energy-related CO_2 emitter countries from 1997 to 2004. The results showed productivity growth rates of 24% over the period attributed to technological progress.

Oh (2010a) measured both good (GDP) and bad (CO_2 and SOx) outputs for twenty-six OECD countries between 1990 and 2003 using the environmentally-sensitive productivity index i.e. the Global Malmquist Productivity Index (GMPI). The results showed that the MI index measured higher productivity growth than the environmentally-sensitive productivity growth indices. Oh, (2010b) employed an environmentally-sensitive productivity growth index to investigate productivity and its components for forty-six countries for the period 1993 to 2003. The author observed that the European countries performed better in the world frontier technology, while the Asian countries were observed to move towards the frontier technology. Zhang et al. (2011) analysed the productivity growth of China from 1989 to 2008 using both MLI and MI. Their findings showed that productivity growth rates for the former approach was 2.46%, whereas the latter was 4.84% suggesting an overestimation of productivity growth when ignoring bad outputs. Lee et al. (2015) analysed the productivity of airlines by incorporating good output and CO_2 emissions using the MLI and found lower productivity growth when including CO_2 in the analysis.

The above overview illustrates that studies that incorporate bad outputs are limited to manufacturing, energy and airline sectors, with no application to the agriculture sector. Further, most the studies have focused on OECD countries, with very few studies on developing countries. So far, no existing study evaluates productivity of African agricultural productivity which incorporate bad outputs. In the absence of empirical evidence, policy-makers face difficulties in ascertaining how the degrading ecosystems due to bad outputs from agriculture is likely to impact negatively on future food production. It also makes it difficult to put in place feasible approaches that would help mitigate bad outputs and assist farmers adopt better farming practices. The current study thus aims to measure African agricultural productivity while incorporating bad outputs using the MLI. The study uses carbon dioxide, nitrogen oxide, and methane to represent bad outputs, while crop and livestock output represent good outputs.

2.4.3 Sources of agricultural total factor productivity (TFP)

Existing studies in the literature use indexes such as the Tornqvist index and MI to measure productivity of a farm or firm. Such studies include Coelli (1995, 1996); Coelli & Rao (2005); Irz, et al. (2001); Jin, et al. (2010); Thirtle, et al. (2003); Thirtle, et al. (1993) and Van Biesebroeck (2007), which decompose TFP into technical and efficiency changes. However, the input-output composition variation - popularly known as the output mix effect while holding the input fixed is rarely discussed in the literature. Further, the varying change in scale and mix efficiency (OSME) that captures the economies of scale and scope effect, is rarely examined. Neither are the output or input mix efficiency components often explored in the existing literature and do not feature in the MI decomposition or interpretation (Coelli, 1995).

The MI change is however not *multiplicatively-complete*[3], since it is only decomposed into technical change and efficiency change. When returns to scale vary and depending on the magnitude of scale economies, the MI may fail to measure productivity change accurately and hence provide biased results (Grifell-Tatjé & Lovell, 1995; O'Donnell (2010, 2012); Peyrache, 2014). Thus, as suggested by Balk (2001) extending the MI using factors which measure scale efficiency change and input (output) mix change is likely to lead to outcomes that better explain TFP change. One such index that captures scale and mix efficiency change is the FPI.

Studies that decompose TFP into other finer components (technical and mix efficiencies) are few in the literature. O'Donnell (2011a) investigated the productivity of the US economy between 1987 and 2008 by calculating the FPI, Lowe and Geometric Young TFP indexes for eighteen manufacturing sectors. The author found that US manufacturers experienced an annual technical progress of only 0.189% on average. The firms were found technically efficient but scale mix inefficient. Thus, the policy implications were that firms needed to change their scale and input mixes to correspond with the changing prices to impact on their mix efficiency levels. O'Donnell (2012b) examined the profitability of U.S. agriculture by calculating the Lowe TFP index and found that technical progress was the driving force of TFP change over the period with an annual average growth rate of 1.84% and 2.3% realised in the 1960s and 1990s respectively. The author found high technical efficiency levels which were stable over the period.

Rahman and Salim (2013) computed a FPI focusing on seventeen Bangladesh regions for the years 1948 to 2008. Results indicated that agricultural TFP change was

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[3] Multiplicatively-complete TFP indexes imply that if the aggregator functions are fixed for all possible binary comparisons then the resulting TFP index satisfies a set of axioms and tests which include monotonicity, linear homogeneity, identity, homogeneity of degree zero, commensurability, proportionality, transitivity and time and space reversal tests as described by O'Donnell (2010).

0.57% per year due to improved technical progress and technical efficiency estimated to be 0.74% and 0.01% per year respectively. However, scale and mix efficiency declined by 0.01% and 0.19% respectively. Tozer and Villano (2013), measured FPI for forty-five Western Australia grain producers using farm level data for the years 2004 to 2007. The results indicated that the producers were technical, mix and scale-efficient, with a difference in efficiency scores occurring in the input mix efficiency and output mix efficiency. The output mix efficiency ranged between 0.48 and 1, with an average of 0.98 while the input mix efficiency ranged between 0.89 and 0.95. Islam et al. (2014) examined farm productivity and profitability of forty-seven broadacre farms of Western Australia over the period 1998 to 2008 using the FPI and found productivity growth to be the key contributing factor of profitability.

This study thus provides comprehensive productivity components of African agriculture by accounting for a wider range of sources of productivity than is not included in the literature on African agriculture. None of the existing studies further decompose TFP into other finer measures for a group of African countries - a gap that this study will fill. Using the FPI, TFP growth of African agriculture is decomposed into technical, efficiency and mix efficiency changes. By deriving more detailed results, it will assist African policy-makers to locate further sources of TFP of African agricultural productivity and thereby identify appropriate and specific policies and practices that will help improve agriculture TFP growth.

2.5 SUMMARY AND IMPLICATIONS

The literature review was examined in many ways. First, existing studies on agricultural productivity for both developed and developing countries were considered, thus providing a general picture of agricultural productivity trends. The gaps identified include:

1. Previous multilateral comparison studies have not examined a case by case and year by year productivity differences or changes for each country.

2. Previous studies have not discussed the policy changes and events for each country. These studies generalise agricultural productivity without providing the reason for the changes.
3. Although there exist in the literature studies that examine productivity in the presence of bad outputs, they are limited to manufacturing and energy sectors of developed countries. No study exists for SSA agriculture. Hence, without such empirical evidence for bad outputs for African nations, it is difficult to identify how improvements should be made to curb GHG emissions, especially considering growing concerns over environmental degradation in many countries.
4. The literature for African productivity is not decomposed into finer components which could allow a better view of the continent’s agricultural productivity growth and assist in drafting policies to promote the same.

This study therefore attempts to fill the identified gaps by first analysing the trends in agricultural productivity in twenty-seven African countries for the period 1980 to 2012 using MI. The study also identifies the significant policy changes and events that may have had an impact on country-specific productivity. Second, the thesis measures African agricultural productivity by incorporating bad outputs, i.e., CO_2, CH_4 and N_2O emissions using the MLI. Last, the thesis uses the FPI to examine other sources of productivity in the selected African countries. The analysis provides results that help identify areas where African agricultural productivity need to be strengthened.

Chapter 3: Research methodology and secondary data sources

3.1 INTRODUCTION

There are two common approaches of deriving meaningful measures of productivity[4] change – the parametric and non-parametric methods.

The non-parametric approach adopts four common methods to measure productivity change. The first method involves measuring output growth net of input growth. Thus, if output grows faster than the inputs used, then the firm achieves productivity growth over time. The second method uses the profitability growth approach to measure productivity change after adjusting for the price movements of the inputs and outputs over time. The third method uses the Caves, Christensen and Diewert (1982) methodology to measure productivity by comparing the observed and the maximum output obtained over time periods with respect to a reference technology. The fourth method, the component-based approach, measures productivity change by identifying various sources of productivity change.

The first approach originated from the works of Hicks and Moorsteen (1961) and Diewert (1992) to capture the changes in output growth net of input growth. The index has an advantage in that the productivity measure and its components are easy to compute and interpret. However, the index lacks a theoretical framework that supports the productivity growth decomposition estimates hence making it difficult to decompose productivity growth into finer sources. The profitability ratio based productivity index uses revenues and costs to measure productivity change after adjusting for changes in input and output price movements over time. However, when there is lack of price data the index cannot be constructed. The third method uses the

[4] In this thesis productivity denotes for a general term while total factor productivity is referred to in Section 3.4. This is because O'Donnell (2010, 2012) and Peyrache (2014) argue that the MI derived by Caves et al. 1982 are not TFP indices.

MI approach to measure productivity growth by using the distance functions to construct the index. The distance functions calculate the radial distance of the observed output and input vectors in period s and t, corresponding to a reference technology (Coelli et al., 2005). Calculating the MI index requires input and output data quantities and does not impose the technical efficiency assumption of the observed firms. Other types of indices used in measuring productivity include the Laspeyres, Tornqvist-Theil, Paasche and Fisher index methods. The fourth method, the component-based approach, measures productivity change by using the product of all the individual sources of productivity, i.e., technical, efficiency, scale and mix efficiency changes (Balk, 2001).

The parametric method adopts the frontier approach to estimate a production, cost or profit function. The parametric form such as the stochastic frontier approach (SFA)'s main weakness includes the fact that it requires a model with a functional form and its strong assumption of how the error term is distributed. Thus, the results obtained are dependent on the type of functional form used, and may thus yield unreliable results especially with a small sample size. When multiple input and output of production technologies are captured, the 'endogeneity' problem when using SFA is common since the independent variables in the econometric model correlate with the error term (O'Donnell, 2014). Although the generalised method of moments (GMM) solves the 'endogeneity' problem by arbitrarily selecting instrumental variables which do not correlate with the error term, GMM still has two key disadvantages. First, the yielded estimates may be sensitive to the choice of instruments considered and, second, the finite sample properties of the estimator may be unknown (O'Donnell, 2014).

The Bayesian methods suggested by Fernandez et al. (2000) offer an alternative solution to the endogeneity problem since the method does not consider the use of instruments. The Bayesian methods estimates the latent dependent variables by drawing the exact finite sample inferences of the variables of the model and its associated measures of efficiency (O'Donnell, 2014). However, in Bayesian modelling, one of the dependent variables is assumed to be unobserved. This study adopts the non-parametric approach. Sections 3.2 and 3.3 discuss the MI and MLI, while sections

3.4 and 3.5 discuss the FPI and the determinants of productivity respectively. The data sources are described in Section 3.6.

3.2 MEASURING PRODUCTIVITY USING INDEX NUMBERS

Productivity, which is an economic measure of the efficiency of production processes, assesses performance by comparing output changes to input levels (Fuglie, 2010). Simple index numbers including the consumer price index, price deflators, finance indexes and import and export price indices remain the most frequently used measures to capture change levels in various economic variables (Coelli, 1995). The index numbers play a key role in measuring output and input changes over time periods and across firms. This study adopts the MI to measure productivity change in African agriculture.

3.2.1 DEA Malmquist Index

The MI is based on DEA, which is a non-parametric linear programming technique that was first proposed by Farrell (1957) and Shephard (1953, 1970). Charnes et al. (1978) first used DEA to evaluate productive efficiency by building on the frontier efficiency concept of Farrell and Shephard. DEA has been used to analyse the efficiency of DMU in many sectors such as agriculture, manufacturing and service industries. DEA has a key advantage in that it can accommodate more than one output and input. Furthermore, it does not require one to specify a functional form to be imposed on the model neither does it need input prices. However, DEA's disadvantage is that it does not provide any statistical inference to its scores.

The MI measures the productivity change of a DMU between two periods. The index captures productivity change by calculating the radial distance between two data points relative to a reference technology frontier. Thus, when computing the MI, four distance functions need to be solved through four different linear programming problems for period t and t+1 for each DMU, as presented in Färe, et al. (1994):

Problem 1: $d^{\mathrm{t}}(x^{\mathrm{t}}, y^{\mathrm{t}})$

$(d^{\mathrm{t}}(x^{\mathrm{t}}, y^{\mathrm{t}}))^{-1} = Max\Phi_1$ (3.1)

Subject to:

$\Phi_1 y_{k,m}^{t} \leq \sum_{k=1}^{K} Z_k\, y_{k,m}^{t}$ m = 1……….M: number of outputs (3.2)

$\sum_{k=1}^{K} Z_k\, x_{k,m}^{t} \leq x_{k,n}$ n = 1………..N: number of inputs (3.3)

$\lambda_{k,n} \geq 0$ k = 1…………K: number of firms (3.4)

Problem 1, when solved, obtains the TE score for the ith firm in the countries based on the production combination and technology for period t.

Problem 2: $d^{\mathrm{t+1}}(x^{\mathrm{t+1}}, y^{\mathrm{t+1}})$

$(d^{\mathrm{t+1}}(x^{\mathrm{t+1}}, y^{\mathrm{t+1}}))^{-1} = Max\Phi_1$ (3.5)

Subject to:

$\Phi_1 y_{j,m}^{t+1} \leq \sum_{k=1}^{K} Z_k\, y_{k,m}^{t+1}$ (3.6)

$\sum_{k=1}^{K} Z_k\, x_{k,m}^{t+1} \leq x_{k,n}$ (3.7)

$\lambda_{k,n} \geq 0$ (3.8)

Problem 2, when solved, obtains the TE score for the ith firm based on the production combination and technology for period t+1.

Problem 3: $d^{\mathrm{t}}(x^{\mathrm{t+1}}, y^{\mathrm{t+1}})$

$(d^{\mathrm{t}}(x^{\mathrm{t+1}}, y^{\mathrm{t+1}}))^{-1} = Max\Phi_1$ (3.9)

Subject to:

$\Phi_1 y_{j,m}^{t+1} \leq \sum_{k=1}^{K} Z_k\, y_{k,m}^{t+1}$ (3.10)

$\sum_{k=1}^{K} Z_k\, x_{k,n}^{t} \leq x_{k,n}$ (3.11)

$\lambda_{k,n} \geq 0$ (3.12)

Problem 3, when solved, obtains the TE score for the ith firm for period t+1 based on the production combination and technology for period t.

Problem 4: $d^{\mathrm{t+1}}(x^{\mathrm{t}},\, y^{\mathrm{t}})$

$$(d^{\mathrm{t+1}}(x^{\mathrm{t}},\, y^{\mathrm{t}}))^{-1} = Max\Phi_1 \qquad (3.13)$$

Subject to:

$$\Phi_1 y_{k,m}^{t} \leq \sum_{k=1}^{K} Z_k\, y_{k,m}^{t} \qquad (3.14)$$

$$\sum_{k=1}^{K} Z_k\, x_{k,n}^{t+1} \leq x_{k,n} \qquad (3.15)$$

$$\lambda_{k,n} \geq 0 \qquad (3.16)$$

Problem 4, when solved, obtains the TE score for the ith firm in the countries for period t based on the production combination and technology for period t+1.

Solving for variable returns to scale (VRS) requires that the following constraint be imposed to the four problems:

$$\sum_{k=1}^{K} \lambda_k = 1 \qquad (3.17)$$

The efficiency scores under the VRS constraint denote pure technical efficiency (PE). The ratio of VRS to constant returns to scale (CRS) give the scale efficiency scores, as follows:

$$SE = \frac{TE_{CRS}}{TE_{VRS}} = \frac{TE_{CRS}}{PE} \qquad (3.18)$$

or: $$\mathrm{TE}_{CRS} = PE\ x\ SE \qquad (3.19)$$

Calculating the decreasing or increasing returns requires the following constraint:

$$\sum_{k=1}^{K} \lambda_k \leq 1 \qquad (3.20)$$

The efficiency scores for constraint (3.20) when equal to the TE scores under CRS, suggests increasing returns to scale (IRS) and decreasing returns to scale (DRS) when the efficiency scores are greater than the TE scores. The four linear programming problems represented by equations (3.1) to (3.16) are solved K times to obtain the solution for each country.

Under constant returns to scale assumption, the MI can thus be expressed as follows:

$$MI = [MI^{t}\text{x}MI^{t+1}]^{\frac{1}{2}} = [\frac{D^{\mathrm{t}}(x^{\mathrm{t+1}}, y^{\mathrm{t+1}})}{D^{\mathrm{t}}(x^{\mathrm{t}}, y^{\mathrm{t}})}\text{x}\frac{D^{\mathrm{t+1}}(x^{\mathrm{t+1}}, y^{\mathrm{t+1}})}{D^{\mathrm{t+1}}(x^{\mathrm{t}}, y^{\mathrm{t}})}]^{\frac{1}{2}} \tag{3.21}$$

The MI is therefore a geometric mean estimate of two Malmquist indexes based on a reference technology frontier in the periods t (M^{t}) and t+1 ($M^{\mathrm{t+1}}$). $D^{\mathrm{t}}(x^{\mathrm{t}},\ y^{\mathrm{t}})$, represents the distance function which measures the distance of a vector of inputs and outputs denoted by x and y respectively. Expression (3.21) can be rewiritten as (3.22) which provides a decomposition of MI into efficiency change and technical change.

$$MI = \frac{D^{\mathrm{t+1}}(x^{\mathrm{t+1}}, y^{\mathrm{t+1}})}{D^{\mathrm{t}}(x^{\mathrm{t}}, y^{\mathrm{t}})}[\frac{D^{\mathrm{t}}(x^{\mathrm{t+1}}, y^{\mathrm{t+1}})}{D^{\mathrm{t+1}}(x^{\mathrm{t+1}}, y^{\mathrm{t+1}})} * \frac{D^{\mathrm{t}}(x^{\mathrm{t}}, y^{\mathrm{t}})}{D^{\mathrm{t+1}}(x^{\mathrm{t}}, y^{\mathrm{t}})}]^{\frac{1}{2}} \tag{3.22}$$

The first component of the MI in Equation 3.22 measures efficiency change (EC) from period t to t+1as follows:

$$EC = \frac{D^{\mathrm{t+1}}(x^{\mathrm{t+1}}, y^{\mathrm{t+1}})}{D^{\mathrm{t}}(x^{\mathrm{t}}, y^{\mathrm{t}})} \tag{3.23}$$

The second component of the Malmquist index in Equation 3.22 measures technical change (TC) from period t to t+1 as follows:

$$TC = [\frac{D^{\mathrm{t}}(x^{\mathrm{t+1}}, y^{\mathrm{t+1}})}{D^{\mathrm{t+1}}(x^{\mathrm{t+1}}, y^{\mathrm{t+1}})} * \frac{D^{\mathrm{t}}(x^{\mathrm{t}}, y^{\mathrm{t}})}{D^{\mathrm{t+1}}(x^{\mathrm{t}}, y^{\mathrm{t}})}]^{\frac{1}{2}} \tag{3.24}$$

Efficiency change is further decomposed into pure technical efficiency (PTE) and scale efficiency (SE) change which is derived by calculating the ratio of two CRS distance functions for two time periods as follows:

$$PTE = \frac{D_{vrs}^{t+1}(x^{\mathrm{t+1}}, y^{\mathrm{t+1}})}{D_{vrs}^{t}(x^{\mathrm{t}}, y^{\mathrm{t}})} \tag{3.25}$$

$$SE = \frac{SE^{\mathrm{t}}(x^{\mathrm{t+1}}, y^{\mathrm{t+1}})}{SE^{\mathrm{t}}(x^{\mathrm{t}}, y^{\mathrm{t}})} * \frac{SE^{\mathrm{t+1}}(x^{\mathrm{t+1}}, y^{\mathrm{t+1}})}{SE^{\mathrm{t+1}}(x^{\mathrm{t}}, y^{\mathrm{t}})}]^{\frac{1}{2}} \tag{3.26}$$

The efficiency change component indicates the gap between the observed and the maximum potential production between the two-time periods while technical change indicates the technology shift between the periods. The efficiency change thus reflects the extent to which decision-making units (DMUs) efficiency improve or worsen, while technical change indicates the change of the efficiency frontiers between two periods. A change in efficiency equal to one suggests that the observed production is closer to maximum point of production in period t+1, while a change of less than one suggests efficiency decline. If the technical change equals to one, there is technical progress given the technology in period t+1. A measure less than one suggests a decline.

3.3 MALMQUIST LUENBERGER PRODUCTIVITY INDEX

Productivity change measurement of African agriculture while considering both good and bad outputs is based on the framework of Chung, et al. (1997). The approach adopts the directional distance function, which considers the reduction of bad outputs while expanding on production of good outputs as defined as follows:

$$\vec{D}_0^{t+1}(x^t, y^t, b^t : g) = \sup\{\beta : (y^t, b^t) + \beta g \in P(x^t)\} \tag{3.27}$$

where $\vec{D}$ represents the directional output distance function which represents the technology while 'g' denotes the vector of directions for scaling the outputs, and g = (y, -b). In this case, y and b denotes good and bad outputs, respectively. Thus, g = (1, -1) implying good outputs are expanded while the bad outputs are reduced. β denotes by how much the good and bad outputs can expand and contract, respectively. Chung, et al. (1997), Färe et al. (2001), Färe, et al. (2007) and Kumar (2006) discuss this in more detail.

Chung, et al. (1997) expresses the MLI for period t and t+1 for a given number of DMUs as:

$$ML_t^t = \frac{[1+\vec{D}_0^{t}(x^{t}, y^{t}, b^{t}; y^{t}, -b^{t})]}{[1+\vec{D}_0^{t}(x^{t+1}, y^{t+1}, b^{t+1}; y^{t+1}, -b^{t+1})]} \tag{3.28}$$

$$ML_t^{t+1} = \frac{[1+\vec{D}_0^{t+1}(x^{t}, y^{t}, b^{t}; y^{t}, -b^{t})]}{[1+\vec{D}_0^{t+1}(x^{t+1}, y^{t+1}, b^{t+1}; y^{t+1} - b^{t+1})]} \tag{3.29}$$

The MLI of productivity change is the geometric mean of the equations 3.28 and 3.29 as follows:

$$ML_t^{t+1} = [\frac{(1+\vec{D}_0^{t}(x^{t}, y^{t}, b^{t}; y^{t}, -b^{t}))}{(1+\vec{D}_0^{t}(x^{t+1}, y^{t+1}, b^{t+1}; y^{t+1}, -b^{t+1}))}\frac{(1+\vec{D}_0^{t}(x^{t}, y^{t}, b^{t}; y^{t} - b^{t}))}{(1+\vec{D}_0^{t+1}(x^{t+1}, y^{t+1}, b^{t+1}; y^{t+1} - b^{t+1}))}]^{1/2} \tag{3.30}$$

The MLI for each period is decomposed into efficiency change and technical change components as follows;

$$MLEFFCH_t^{t+1} = [\frac{(1+\overrightarrow{D_0}^{t}(x^{t}, y^{t}, b^{t}; y^{t}, -b^{t}))}{(1+\overrightarrow{D_0}^{t}(x^{t+1}, y^{t+1}, b^{t+1}; y^{t+1}, -b^{t+1}))}]^{1/2} \quad (3.31)$$

$$MLTECH_t^{t+1} = [\frac{(1+\overrightarrow{D_0}^{t+1}(x^{t}, y^{t}, b^{t}; y^{t}, -b^{t}))\,(1+\overrightarrow{D_0}^{t+1}(x^{t+1}, y^{t+1}, b^{t+1}; y^{t+1}, -b^{t+1}))}{(1+\overrightarrow{D_0}^{t}(x^{t}, y^{t}, b^{t}; y^{t}, -b^{t}))\,(1+\overrightarrow{D_0}^{t}(x^{t+1}, y^{t+1}, b^{t+1}; y^{t+1}, -b^{t+1}))}]^{1/2} \quad (3.32)$$

The efficiency change represents the output changes between the periods while the technical change represents the shift in the technology frontier.

If $x^t = x^{t+1}, y^t = y^{t+1}$, and $b^t = b^{t+1}$ it implies that there are no feasible changes in input or output quantities between periods, suggesting that the ML_t^{t+1} productivity index is equal to 1. When productivity improves, the ML_t^{t+1} productivity index becomes greater than 1 and vice versa when a decline occurs. A $MLTECH_t^{t+1}$ score of greater than 1 suggests a positive shift of the production frontier in favour of good output while decreasing the bad output and vice versa. A $MLEFFCH_t^{t+1}$ score of larger than 1 implies that the production is located closer to the frontier in period t+1 than in period t and vice versa.

The MLI is computed by solving the four distance functions specified in the linear programme. Based on period t….T and k = 1……..K countries', the input and output model is defined as:

$$P(x) = (y, b): \sum_{k=1}^{K} z_k y_{km}^t \geq y_{km}^t \qquad m = 1, \dots \dots \dots, M \quad (3.33)$$

$$\sum_{k=1}^{K} z_k^t b_{kj}^t = b_j^t \qquad j = 1, \dots \dots \dots, J \quad (3.34)$$

$$\sum_{k=1}^{K} z_k^t x_{kn}^t \leq x_n^t \qquad n = 1, \dots \dots \dots, N \quad (3.35)$$

$$z_k \geq 0 \qquad k = 1, \dots \dots \dots, K \quad (3.36)$$

The inequality constraint in Equation (3.33) on the good outputs, y_{km}^t, m=1,… M imply that good outputs are freely disposable. This inequality constraint on the good output implies that cutting back on the use of inputs can reduce the good output. Combining the equality constraint in Equation (3.34) on the bad outputs, $(b_j^t, j = 1, \dots J)$, our model will then comprise good and bad outputs that are weakly disposable. That is, it will be costly to dispose of the bad output.

The output set satisfies the assumption of CRS, which indicates that inputs and outputs will be increasing at the same rate and under the assumption that inputs are strongly disposable. That is,

$$\mathrm{P}(\lambda \mathrm{x}) = \lambda \mathrm{P}(\mathrm{x}), \lambda > 0 \qquad (3.37)$$

$$x' \geq \mathrm{x} \Rightarrow \mathrm{P}(x') \supseteq \mathrm{P}(\mathrm{x}) \qquad (3.38)$$

The MLI is computed using the directional distance functions by solving the following linear programme problems:

$$\overrightarrow{D_0^t}(\mathrm{x}^{\mathrm{t,k'}}, \mathrm{y}^{\mathrm{t,k'}}, b^{t,\mathrm{k'}};\ y^{t,\mathrm{k'}}, -b^{t,\mathrm{k'}}) \ = \ \mathrm{Max}\,\beta \qquad (3.39)$$

Subject to:

$$\textstyle\sum_{k=1}^{K} z_k^t y_{km}^t \ \geq (1 + \beta)\, y_{\mathrm{k'm}}^t \qquad m = 1, \dots \dots \dots, M \qquad (3.40)$$

$$\textstyle\sum_{k=1}^{K} z_k^t b_{ki}^t = (1 - \beta)\, b_{\mathrm{k'i}}^t \qquad j = 1, \dots . \dots \dots, J \qquad (3.41)$$

$$\textstyle\sum_{k=1}^{K} z_k^t x_{kn}^t \leq x_{\mathrm{k'n}}^t \qquad n = 1, \dots \dots \dots, N \qquad (3.42)$$

$$z_k^t \geq 0 \qquad k = 1, \dots \dots \dots, K \qquad (3.43)$$

In this study, a two-year window reference technology is employed. For example, the frontier for 1981 would be constructed using data for 1980 and 1981.

3.3.1 Modelling bad outputs in DEA method

A useful approach to incorporating bad outputs in estimating efficiency is one that allows an explicit modelling of a joint environmental technology, and benchmarks the DMUs by factoring the increase of good output while reducing bad output. The property of being weakly disposable allows the possibility of modelling at least one bad output in the production function. For example, the output set P(x) represents the good outputs set denoted as $y \in \mathfrak{R}_T^M$ and bad output denoted as $u \in \mathfrak{R}_T^K$, which are produced from the input vector, $\mathrm{x} \in \mathfrak{R}_T^N$. If the output set $P(x)$, $x \in \mathfrak{R}_T^N$ is a closed and bounded set and free disposability of the inputs is assumed, then P(x) becomes an environmental output set if $(\mathrm{y}, \mathrm{u}) \ \in P(x)$ and $0 \leqq \theta \leqq 1$, and, thus occurs within the set $(\theta y, \theta u) \in P(x)$. If null jointness exists for good and bad outputs, then,$(\mathrm{y}, \mathrm{u}) \in P(x)$, $u = 0$, which indicates that $y = 0$ whereby y is denoted as the good output and u denote is denoted as the bad output. Thus, if there are k observations, the modelling of the environmental output set in a DEA framework becomes;

$$P(X) = \{(y, u): \sum_{k=1}^{K} s_k y_m \geqq y_m \qquad m = 1, \ldots \ldots, M \tag{3.44}$$

$$\sum_{k=1}^{K} s_k u_{kj} = u_j, \qquad j = 1, \ldots \ldots \ldots, J \tag{3.45}$$

$$\sum_{k=1}^{K} s_k x_{kn} = x_n, \qquad n = 1, \ldots \ldots \ldots, N \tag{3.46}$$

$$s_k \geqq 0. \qquad k = 1, \ldots \ldots \ldots, K \tag{3.47}$$

where, $s_k, k = 1, \ldots \ldots \ldots \ldots, K$, denote for non-negative intensity variables that capture the CRS assumption.

Considering the bad outputs, the following restrictions are imposed for the null jointness assumption;

$$\sum_{k=1}^{K} u_{kj} > 0, \qquad j = 1 \ldots \ldots \ldots J, \tag{3.48}$$

$$\sum_{k=1}^{K} u_{kj} > 0, \qquad k = 1 \ldots \ldots \ldots K. \tag{3.49}$$

Thus, DEA computes the DMUs' efficiency scores using the directional distance function which models both good and bad outputs. The distance function allows the good outputs to be maximised while minimising the bad outputs simultaneously. h = (h_y, -h_u) is the direction vector and DMU k's efficiency score is obtained by solving the linear programming problem as follows;

$$\vec{D}_0(\mathrm{x\,k'}, \mathrm{y\,k'}, \mathrm{u\,k'};\ \mathrm{h}) = \mathrm{Max}\,\beta \tag{3.50}$$

Subject to:

$$\sum_{k=1}^{K} s_k y_{km} \geqq \mathrm{y}_{\mathrm{k'm}} + \beta \mathrm{h}_{ym} \qquad m = 1, \ldots \ldots \ldots, M \tag{3.51}$$

$$\sum_{k=1}^{K} s_k u_{kj} = \mathrm{u}_{\mathrm{k'j}} - \beta \mathrm{h}_{ym} \qquad j = 1, \ldots \ldots \ldots, J \tag{3.52}$$

$$\sum_{k=1}^{K} s_k x_{kn} \leqq x_{\mathrm{kn}} = \mathrm{u}_{\mathrm{k'j}} - \beta \mathrm{h}_{ym} \qquad n = 1, \ldots \ldots \ldots, N \tag{3.53}$$

$$s_k \geqq 0 x_{\mathrm{kn}} = \mathrm{u}_{\mathrm{k'j}} - \beta \mathrm{h}_{ym} \qquad k = 1, \ldots \ldots \ldots, K \tag{3.54}$$

3.4 FÄRE-PRIMONT TFP INDEX

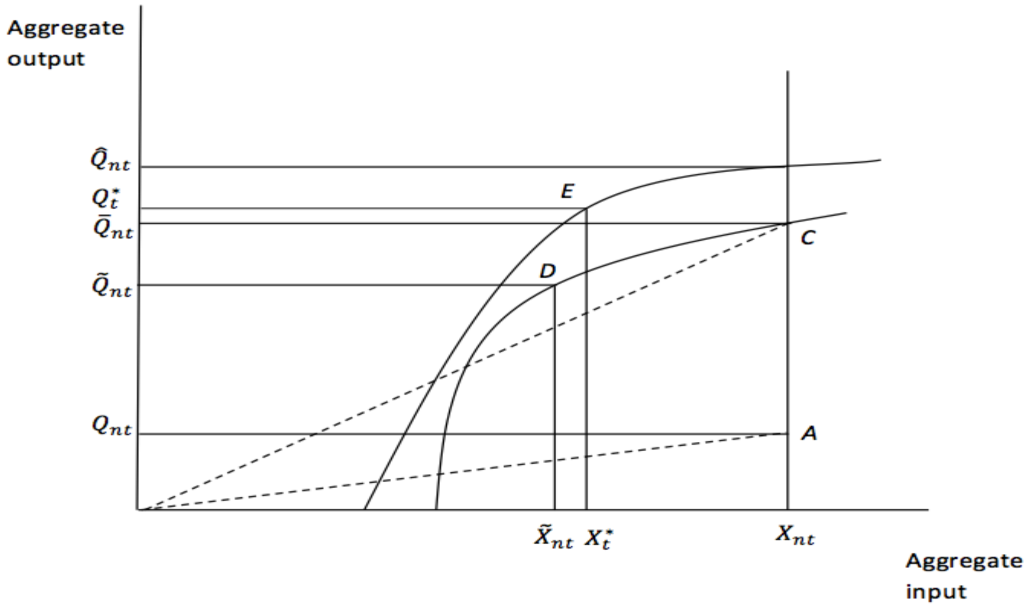
In this study, the total factor productivity of African agriculture and its components are evaluated using the FPI analytical framework developed by O'Donnell (2012) and its corresponding software decomposition of productivity index (DPIN) version 3.0 (O'Donnell, 2011). The approach uses aggregate quantity framework to represent the underlying production technology. The TFP changes of a given firm are computed by taking the ratio of the aggregate output to the aggregate input (O'Donnell, 2010; 2012). The advantage of the aggregate framework is that it does not require imposing of any assumptions on the production technology such as specifying a cost or profit maximisation model, defining the firms' market structure nor specifying the returns to scale for the production technology. Following, O'Donnell (2012), we assume that the input quantity is $x_{nt} = (x1_{nt}, \dots \dots .., xK_{nt})$' and the output quantity is $q_{nt} = (q1_{nt}, \dots \dots \dots qj_{nt})'$ of firm *n* while *t* denotes the number of periods. Thus, a firm's TFP in period t is expressed as:

$$TFP_{nt} = \frac{Q_{nt}}{X_{nt}} \tag{3.55}$$

where $(Q_{nt}) = Q(q_{nt})$ and $(X_{nt}) = X(X_{nt})$ which denotes the aggregate output and input quantities of firm *n* in period *t*. The FPI aggregator functions possess desirable properties such as nonnegativity, non-decreasing and transitivity. The FPI which compares the TFP of firm *n* and *h* in period *t* and *s* becomes:

$$TFP_{hs,nt} = \frac{TFP_{nt}}{TFP_{hs}} = \frac{\frac{Q_{nt}}{X_{nt}}}{\frac{Q_{hs}}{X_{hs}}} = \frac{Q_{nt}}{X_{hs}} \tag{3.56}$$

where $Q_{nt} = \frac{Q_{nt}}{Q_{hs}}$ represents the output quantity index and $X_{nt} = X_{nt}/X_{hs}$ represent the input quantity index of firm n in period t as defined by O'Donnell (2010). The FPI aggregator functions express TFP growth as a ratio of output growth to input growth and further decompose TFP into technical, mix and residual scale efficiency measures (O'Donnell, 2012). The analytical form is presented in Figure 3.1.



Source: O'Donnell (2010)

Figure 3.1 Components and measures of TFP

The efficiency measures are determined by whether the production technology is output or input oriented. Output oriented maximises output by expanding the output given the inputs, while input oriented minimises inputs while holding the output constant. In this study, the output oriented model becomes a more realistic scenario since farmers expect to maximise output. The output-oriented technical efficiency is measured as:

$$OTE_{nt} = \frac{Q_{nt}}{\bar{Q}_{nt}} \leq 1 \tag{3.57}$$

While output oriented scale-efficiency is denoted as follows:

$$OSE_{nt} = \frac{\bar{Q}_{nt}}{X_{nt}} / \frac{\tilde{Q}_{nt}}{\tilde{X}_{nt}} \leq 1 \tag{3.58}$$

Output oriented mix efficiency is defined as:

$$OME_{nt} = \frac{\bar{Q}_{nt}}{\hat{X}_{nt}} \leq 1 \tag{3.59}$$

The residual output scale efficiency is defined as:

$$ROSE_{nt} = \frac{\hat{Q}_{nt}}{X_{nt}} / \frac{Q_t^*}{X_T^*} \leq 1 \tag{3.60}$$

The residual mix efficiency is defined as:

$$RME_{nt} = \frac{\tilde{Q}_{nt}}{\tilde{X}_{nt}} / \frac{Q_t^*}{X_T^*} \leq 1 \qquad (3.61)$$

where $\bar{Q}_{nt}$ denotes the maximum aggregate output feasible from an input set of X_{nt} with a scalar multiple of q_{nt}, while $\hat{Q}_{nt}$ denotes the maximum aggregate output obtained from X_{nt} set of inputs. $\tilde{Q}_{nt}$ denotes the aggregate output obtained while $\tilde{X}_{nt}$ is the aggregate input used subject to the input and output quantities being scalar quantities of q_{nt} and x_{nt} when maximising TFP (O'Donnell, 2010). Q_t^* and X_T^* denote the aggregate output and input respectively at maximum TFP (denoted as TFP_{nt}^*) given technology. The ratio of observed TFP to the maximum possible TFP given the technology gives the overall productive efficiency (O'Donnell, 2012), denoted as $TFPE_{nt}$ which can be represented as follows:

$$TFPE_{nt} = \frac{TFP_{nt}}{TFPE_t^*} = \frac{\frac{Q_{nt}}{X_{nt}}}{\frac{Q_{nt}^*}{X_{nt}^*}} = OTE_{nt} * OME_{nt} * ROSE_{nt} = OTE_{nt} * OSE_{nt} * RME_{nt} \leq 1 \qquad (3.62)$$

The productive efficiency input orientation can be expressed as:

$$TFPE_{nt} = ITE_{nt} * IME_{nt} * RISE_{nt} = ITE_{nt} * ISE_{nt} * RME_{nt} \leq 1 \qquad (3.63)$$

Where

$$ITE_{nt} = \frac{\bar{X}_{nt}}{X_{nt}} \leq 1 \qquad (3.64)$$

$$ISE_{nt} = \frac{Q_{nt}}{\bar{X}_{nt}} / \frac{\tilde{Q}_{nt}}{\tilde{X}_{nt}} \leq 1 \qquad (3.65)$$

$$IME_{nt} = \frac{\hat{X}_{nt}}{\bar{X}_{nt}} \leq 1 \qquad (3.66)$$

$$RISE_{nt} = \frac{Q_{nt}}{\tilde{X}_{nt}} / \frac{Q_t^*}{X_T^*} \leq 1 \qquad (3.67)$$

The TFP and its components is estimated through the Färe-Primont aggregator functions as follows:

$$Q(q) = D_0(X_0, q, t_0) \qquad (3.68)$$

$$X(x) = D_1(x, q_0, t_0) \qquad (3.69)$$

where q and x are the output and input vectors respectively. $D_0(.)$ and $D_1(.)$ represent the output and input distance function respectively. The Färe-Primont productivity index as denoted by O'Donnell (2011) is as follows:

$$TFP_{hs,nt} = \frac{D_0(X_0 q_{nt} t_0)}{D_0(X_0 q_{hs} t_0)} * \frac{D_1(X_{hs} q_0 t_0)}{D_1(X_{nt} q_0 t_0)} \quad (3.70)$$

If the output distance function D_0(.) and the aggregator functions Q(.) and X(.) were known in theory the following can be computed:

$$TFP_{nt} = \frac{Q(q_{nt})}{X(x_{nt})} \quad (3.71)$$

where t = 1, ...T; $TFP^*_{nt} = max > 0, q \geq 1$ represents the maximum TFP obtained from a given technology:

$$TFPE_{nt} = \frac{TFP_{nt}}{TFP^*_{nt}} \quad (3.72)$$

Where t = 1, ...T, which is referred to as TFP efficiency.

The Färe-Primont index input distance function is expressed as follows:

$$D_1(x_{nt}, q_{nt}, t) = (x'_{nt}\eta)/(q'_{nt}\emptyset - \delta) \quad (3.73)$$

The input orientation involves choosing values of the unknown parameters that would maximise technical efficiency: $ITE_{nt} = D_1(x_{nt}, q_{nt}, t)^{-1}$. The resulting LP would be:

$$ITE_{nt} = D_1(x_{nt}, q_{nt}, t)^{-1} = ITE_{nt} = \max\{q'_{nt}\emptyset - \delta : \boldsymbol{Q}'\emptyset \leq \delta_t + \boldsymbol{X}'\beta; x'_{nt}\eta = 1; \emptyset \geq 0; \eta \geq 0\} \quad (3.74)$$

The FPI is thus computed as a ratio of aggregate outputs to aggregate inputs as follows:

$$Q_{nt} = (q'_{nt}\alpha_0)/(\gamma_0 + x'_0\beta_0) \quad (3.75)$$

$$X_{nt} = (x'_{nt}\eta_0)/(q'_0\emptyset_0 - \delta_0) \quad (3.76)$$

where $\alpha_0, \gamma_0, \beta_0, \eta_0, \emptyset_0$ and δ_0 solve for equations 3.75 and 3.76 in the Decomposition of Productivity Index (DPIN version 3.0) software using the sample mean vectors to represent the output and input vectors.

In this study, the output orientation direction of movement to the production frontier is considered with varying technical change and CRS of the representative technology.

3.5 DETERMINANTS OF TFP

Using the TFP scores from the FPI model, the determinants of TFP were investigated using the Bayesian modelling average (BMA) technique, as described below.

3.5.1 Bayesian modelling average technique (BMA)

The traditional method for data analysis often ignores the issue of model uncertainty through the assumption that the model chosen has generated the data. One method that addresses the model uncertainty is the BMA technique. BMA first became famous in statistics in the mid-1990s through its use to solve uncertainty when selecting models (Madigan & Raftery, 1994; Raftery, 1995). Since then, many disciplines such as economics (Bunnin et al., 2002; Chua et al., 2001; Fernández et al., 2001b); biology (Yeung et al., 2005); ecology (Wintle et al., 2003); and medicine (Oehler et al., 2009) have adopted BMA as a tool of analysis. Thus, when there exists a possibility of more than one competing approach being applied to the same theoretical concept, use of BMA techniques makes it easier to assess the data in favour of one or other of the approaches. Again, when uncertainty occurs over which control variables and models to use, then the robustness of the results is tested by calculating posterior distributions.

Analysing TFP determinants faces a major challenge in the form of model uncertainty because there is an inadequately strong theoretical basis to determine which control variables affect TFP, and which model will correctly specify the determinants. Thus, the BMA becomes important in identifying the TFP determinants of African agriculture.

3.5.2 Review of Bayesian modelling average technique

A linear model structure with the dependent variable y, a constant denoted as α, several coefficients denoted as β and a normally distributed error term ε with variance σ^2, can be represented as follows:

$$y = \alpha + \beta_i X_i + \varepsilon \qquad \varepsilon \sim N(0; \sigma^2) \tag{3.77}$$

However, when several potential explanatory variables in a matrix X exist, then it becomes difficult to know which variables to include, and how important they are. BMA solves the uncertainty problem by approximating models for all possible sets of X and constructing a weighted average over all the variables. If X contains K possible variables, then an estimate of 2^k models will be made which implies that the anticipated number of explanatory variables in a model will be k/2 (Fernández et al., 2001a). The model weights for the averaging stem from posterior model probabilities over models M is thus expressed as:

$$P(M_k|y, X) = \frac{p(y|M_k, X)p(M_k)}{p(y|X)} = \frac{p(y|M_k, X)p(M_k)}{\sum_{s=1}^{2k} p(y|M_s, X)p(M_s)} \tag{3.78}$$

where $P(M_k|\, y, X)$ denotes for the posterior model probability, $p(y|X)$ is the integrated likelihood which is a multiplicative term, and p(M) denotes the prior model probability. Thus, the posterior model probability of a given model is defined as the model likelihood conditional on the assumed model M times a prior model probability. Thus, the weighted posterior distribution for any data is denoted as:

$$\theta: \sum_{\gamma=1}^{2k} p(\theta|M, y)p(M|X, y). \tag{3.79}$$

3.5.3 Bayesian modelling average in R software

Following the works of Fernández, et al. (2001b), we assess the BMA of TFP output value and environmental variables which include: political stability, agricultural spending, HIV prevalence, mean years of schooling, area irrigated and per capita land. The BMA was implemented through the Markov chain Monte Carlo model composition (MC3) algorithm using R software which builds the dataset into Bayesian model sampling (BMS) package. The estimates were by generated by running 200,000 observations, and then discarding the first 100,000 as a "burn-in". The mprior was set to uniform prior on model probabilities with the g prior set to g = max(N, K^2) via the argument g=" BRIC".

3.6 SECONDARY DATA SOURCES

Data was drawn from the Food and Agriculture Organization statistical database (FAOSTAT, 2014) to analyse the productivity of African agriculture for twenty-seven African countries. The concepts and measurement used by the FAO remain consistent across countries, thus allowing international comparison. A balanced[5] panel dataset covering the period 1980-2012 was used for the following countries: Algeria, Angola, Burkina Faso, Burundi, Cameroun, Côted'Ivoire, Egypt, Gabon, Gambia, Ghana, Kenya, Libya, Madagascar, Malawi, Mali, Mozambique, Niger, Nigeria, Rwanda, Sudan (former), South Africa, Tanzania, Togo, Tunisia, Uganda, Zambia and Zimbabwe. Twenty-seven other African countries excluded from the analysis in order to achieve a balanced panel dataset were: Benin, Botswana, Cape Verde, Central African Republic, Comoros, Democratic Republic of Congo, Djibouti, Equatorial Guinea, Ethiopia, Guinea-Bissau, Liberia, Mauritania, Eritrea, Mauritius, Morocco, Guinea, Namibia, São Tomé and Príncipe, Lesotho, Republic of the Congo, Senegal, Seychelles, Somalia, South Sudan and Swaziland.

Using panel data has many advantages. First, panel data involves pooling the data, which generates a more accurate prediction of individual outcomes than making predictions of different outcomes using individual observations data (Hsiao, 2007). Second, panel data tends to blend both between and within individual differences of the sample, thereby providing better inferences of model parameters than when using time series or cross-sectional data. Third, panel data offers more sample variability and degrees of freedom than the use of cross-sectional datasets.

3.6.1 Output variables

The output variables consisted of two good outputs namely, crops and livestock, and three bad outputs CO_2, CH_4 and N_2O emissions. The disaggregation of the data into crop and livestock output is an advantage since it gives performance

[5] Balanced data refers to the fact that all countries have data for all years

benchmarks that are more accurate than the aggregated, which sometimes gives potentially misleading and even inaccurate estimates (Zhu, 2016). Crop and livestock output was based on gross production value expressed in constant 2005 international dollars as provided in Rao (1993) detailed description and assessment of data aggregation. The study considered the seasonality of the output variable due to factors such as weather, which would otherwise make it difficult to differentiate the short-run changes from long-term trends. The application of data smoothing for each country helped account for these fluctuations. Although Ravn and Uhlig (2002) recommend the use of the Hodrick-Prescott filter, the nonlinear smoothing with a span of 5 technique was adopted since it produced better estimates consistent with the observed data than the Hodrick- Prescott filter or exponential smoothing methods.

The bad outputs were the agriculture GHG measured in metric tonnes. The FAOSTAT GHG data is based on country-level estimates following FAOSTAT activity data computed using Tier 1 - which complies with the 2006 Intergovernmental Panel on Climate Change (IPCC) Guidelines for National GHG Inventories.

3.6.2 Input variables

In agricultural productivity analysis, the four commonly used direct inputs are land, labour, number of tractors, which represents capital, and materials (fertiliser). This study used gross capital stock rather than the number of tractors, since tractor use among the small-scale African farmers remains very low. The input variables used comprises the following:

- *Land*: This is the number of hectares of arable land and land under permanent crops and pasture.
- *Labour*: Labour is defined as the total population that actively participates and earns either a wage, salary, commission, piece rate or pay in kind in agriculture.
- *Gross capital stock*: This is the total physical assets for land development, livestock (fixed assets and inventory), machinery and equipment and

livestock structures in 2005 constant prices. Capital stock is used as an input instead of tractors because there is low tractor use among small-scale farmers in Africa, again FAO data does not provide a balanced panel dataset for most countries due to missing values. To compare across countries, the data was deflated using the purchasing power parity (PPP) conversion factors from the World Bank as shown in Table 3.1, with Malawi as a base. FAO calculates the capital stock for all other countries using the double declining balance method with an assumed depreciation rates that range from 0.03 to 0.08 subject to the economic level of the countries.

- *Fertiliser*: This refers to the quantity of all fertilisers used measured in tonnes.
- *Livestock*: This is the sum of animals (asses, horses, mules, cattle, sheep, pigs and goats) converted into sheep equivalent using the following conversion factors: asses and cattle (0.8), camels (1.1), goats and sheep (0.1), pigs (0.2), and horses and mules (1). Chicken numbers were not included due to their short lifespan.
- *Rainfall*: This is the average annual precipitation measured in millimetres. Since African agriculture is largely rain-fed, the variable is considered as 'non-market' or non-discretionary production input (Henderson & Kingwell, 2005; Wiebe et al. 2003; Craig et al. 1997). The rainfall data was obtained from the World Bank and Mitchell et al. (2004) and Jefferson & O'Connell (2004) databases.

The statistics of the variables used in the analysis are summarised in Table 3.2. The MI and MLI were obtained using the Max DEA Pro Version 6.0 software. The CRS assumption relating to the production technology is imposed especially when using an aggregate of different countries, since capturing the difference in scale becomes irrelevant (Coelli & Rao, 2005). Thus, given the countries 'endowments' such as the land size, population and the available natural resources remain as given, and cannot therefore be decisive factors, the CRS assumption relating to the underlying technology was more appropriate than the VRS assumption. CRS was also preferred because Malmquist-type productivity estimates tend to be biased under VRS technology as observed by Grifell-Tatjé and Lovell (1995).

The third study decomposed productivity growth into technical, scale and mix efficiency change using the DPIN Version 3.0 from the Centre for Efficiency and Productivity Analysis (CEPA) of the School of Economics, University of Queensland website.

3.6.3 Environmental variables

The variables used include agriculture research spending, labour ratio, HIV prevalence, area irrigated, rainfall, governance, per capita land and average years of schooling. The Agricultural Science and Technology Indicators (ASTI) database of the International Food Policy Research Institute (IFPRI) provided the data for agriculture research spending for the countries studied. The United Nations Development Programme (UNDP) website provided the average years of schooling data, which was at 5-year intervals for the period 1980-1990/2000-2005 and 10-year intervals for the period 1990-2000, with averages used to cover the years in between. The rest of the data variables utilised for this stage were obtained from the World Bank website.

The productivity determinants are as summarised below:

- *Agricultural spending*: This is the total expenditure on salary-related expenses, operating and program costs, and capital financing by state, non-profit, and higher education agencies for agriculture research. Thus, it serves as a proxy for technology progress.
- *Irrigated area*: This refers to the total agricultural area in hectares equipped for irrigation as a proxy of land quality.
- *Governance:* This was defined using the World Bank governance index. Dummies were assigned to capture political (in)stability. Countries that had a positive index suggested political stability hence were assigned 1, while those with a negative index were designated 0 to imply political instability.

- *Per capita land*: This is represented by the ratio of agricultural land to the agricultural population which served as a proxy for land size.
- *Education:* This refers to the average years of education attained by people of ages twenty-five years and above which served as a proxy for a country's education attainment.
- *HIV prevalence:* This refers to the HIV prevalence percentage of the population of ages fifteen years and above. Given Africa is highly prone to HIV, the variable serves as a proxy for human well-being.

The determinants of productivity change were established using the BMA technique in R software.

Table 3.1 Purchasing power parity conversion

Country	2005 PPP conversion factor, GDP	PPP deflator with Malawi as base year
Algeria	31.81	0.81
Angola	44.49	1.13
Burkina Faso	200.23	5.07
Burundi	342.96	8.69
Cameroon	251.02	6.36
Cote d'Ivoire	287.49	7.29
Egypt	1.62	0.04
Gabon	256.23	6.49
Gambia	7.56	0.19
Ghana	0.37	0.01
Kenya	29.52	0.75
Libya	0.73	0.02
Madagascar	649.55	16.46
Malawi	39.46	1.00
Mali	240.09	6.08
Mozambique	10.91	0.28
Niger	226.66	5.74
Nigeria	60.23	1.53
Rwanda	186.18	4.72
South Africa	3.87	0.10
Sudan	1.08	0.03
Togo	395.63	10.03
Tunisia	240.38	6.09
Uganda	619.64	15.70
Tanzania	0.58	0.01
Zambia	2.41	0.06
Zimbabwe	122.00	3.09

Source: The World Bank (2005)

Table 3.2 Summary statistics for the variables

Variable	Mean	Min	Max	STDEV
Good Output				
Crops (2005 international $)	2955592	51834	33900000	4638364
Livestock (2005 international $)	992482.2	16415	6704371	1291433
Bad output				
CO_2 emissions (1,000 metric tonnes)	15239.5	86.9	110220.3	17909.5
CH_4 emissions (1,000 metric tonnes of CO_2 equivalent)	7807.1	30.2	59866.2	9594.3
N_2O emissions (1,000 metric tonnes CO_2 equivalent)	6985.3	55.6	50094.2	8139.9
Inputs				
Capital stock (2005 international $)	124060.4	46.1	1846596	299361.2
Total agricultural land (1,000 ha)	27852.6	495	136698	29842.1
Total agricultural population (1,000)	4138.5	60	17851	3453.0
Fertiliser (tonnes)	147630.7	1.0	1840399	274532.3
Livestock (1000 head)	6386555	44796.4	49798085	8073908
Rainfall (mm)	959.3	29.4	3075.4	521.3
Determinants of productivity				
Agriculture research expenditure (million 2011 PPP $)	69.01	0.90	967.70	126.25
Irrigation (1000 ha)	3.93	0.00	36.50	7.36
Governance (1 = stable; 0 = otherwise)		0	1	
HIV prevalence (%)	5.01	0.10	29.60	5.82
Per capita land (ha)	11.23	0.05	239.86	31.61
Education (years)	4.23	0.65	9.70	1.94

Source: FAOSTAT 2013 & The World Bank 2014 and others

Chapter 4: Results for agricultural productivity

4.1 INTRODUCTION

This chapter provides the results for productivity change and its components for the three studies. Section 4.2, which presents productivity change patterns for the period 1980-2012 using the MI indices, addresses the first objective of the thesis by establishing the trends in productivity change in African countries. Section 4.3 provides the productivity change when undesirable output is included by using the MLI, thus addressing Objective Two of the thesis by providing the environmentally adjusted productivity change. Section 4.4 provides the results of the FPI, thus addressing Objective Three of the thesis by decomposing productivity change into finer components, and by establishing the determinants of productivity change.

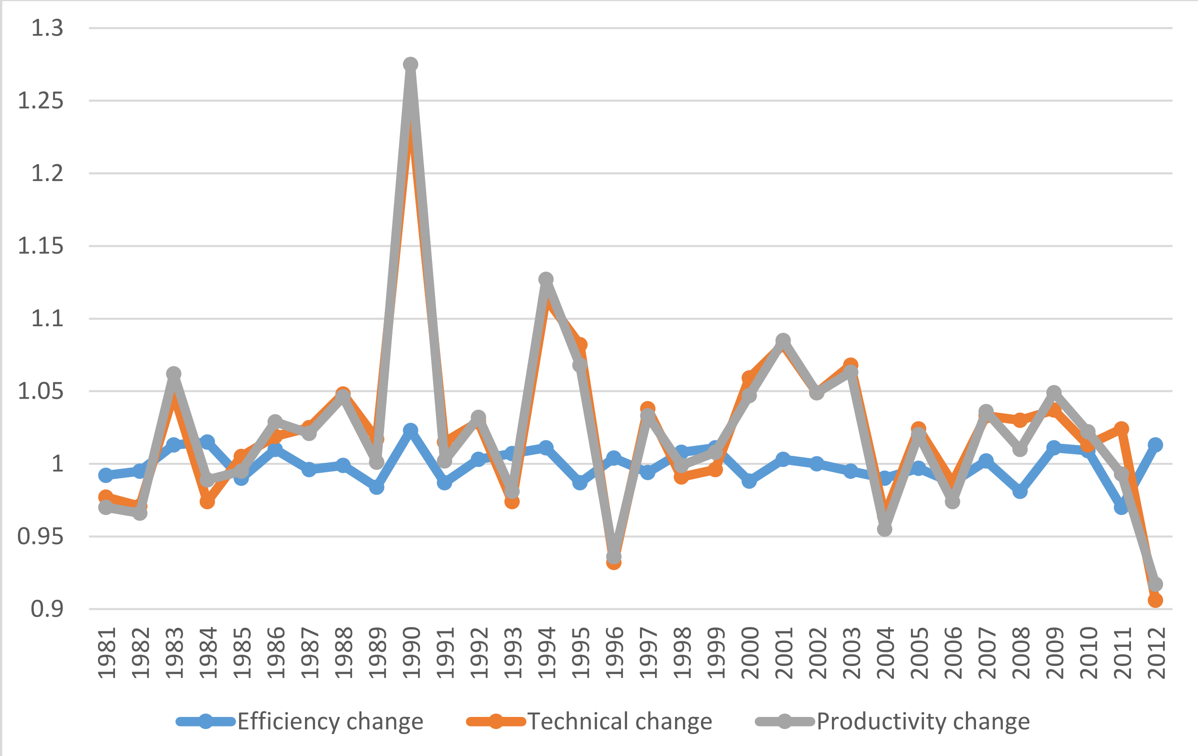
4.2 PRODUCTIVITY CHANGES AND ITS COMPONENTS FOR THE PERIOD 1980-2012

This section addresses productivity changes and its components for the period 1980-2012 and over the years. The section also compares productivity across countries and regions and provides the technology gap ratios.

4.2.1 Productivity annual means

The estimates for the MI annual means and its components of efficiency change, technical change, pure technical efficiency change and scale efficiency change, are provided in Table 4.1. The mean productivity change, technical change and efficiency change was 2.2%, 2.3% and -0.1%, respectively, with Figure 4.1 showing the trends over time. Pure technical efficiency change declined by 0.1% with scale efficiency remaining constant.

Productivity change increase or decline coincided with the changing weather patterns. For example, drought in 1981/1982, floods in 1989, 1992 and 2001 in some countries led to an average productivity decline. During good rainfall years, such as 1984, 1988, 1990, 2002 and 2007, the countries produced a bumper harvest, thus increasing productivity (Von Braun et al.,1999). The year 1994 experienced a high in productivity change of 12.8% due to greater technical change, while 2004 experienced a substantive productivity decline of 4.5% due to low efficiency, technical, pure and scale efficiency changes. The low pure efficiency, especially during the drought years, means that the farmers failed to adjust the direct inputs to the weather changes. It can therefore be concluded that African agricultural productivity growth emanated from technical progress during the period 1980-2012.



Source: Results estimates

Figure 4.1 Productivity changes and its components: 1981-2012

Table 4.1 Malmquist index summary of annual means

Year	Efficiency change	Technical change	Pure efficiency	Scale efficiency	Productivity change
1981*	0.992	0.977	1.003	0.990	0.970
1982	0.995	0.971	0.988	1.007	0.966
1983	1.013	1.048	1.004	1.009	1.062
1984	1.015	0.974	1.022	0.994	0.989
1985	0.990	1.005	0.983	1.007	0.995
1986	1.010	1.019	1.006	1.004	1.029
1987	0.996	1.025	1.016	0.980	1.021
1988	0.999	1.048	0.987	1.012	1.046
1989	0.984	1.017	1.002	0.982	1.001
1990	1.023	1.246	0.996	1.027	1.275
1991	0.987	1.015	0.981	1.006	1.002
1992	1.003	1.029	1.026	0.977	1.032
1993	1.007	0.974	0.978	1.030	0.981
1994	1.011	1.114	1.032	0.980	1.127
1995	0.987	1.082	0.983	1.004	1.068
1996	1.004	0.932	0.998	1.007	0.936
1997	0.994	1.038	0.987	1.007	1.033
1998	1.008	0.991	1.017	0.991	0.999
1999	1.011	0.996	1.014	0.997	1.008
2000	0.988	1.059	0.979	1.010	1.047
2001	1.003	1.082	0.994	1.009	1.085
2002	1.000	1.049	0.997	1.003	1.049
2003	0.995	1.068	1.003	0.992	1.063
2004	0.990	0.964	0.990	1.001	0.955
2005	0.997	1.024	1.006	0.991	1.020
2006	0.987	0.987	0.988	0.998	0.974
2007	1.002	1.033	0.994	1.009	1.036
2008	0.981	1.030	0.979	1.002	1.010
2009	1.011	1.037	1.033	0.979	1.049
2010	1.009	1.013	1.007	1.002	1.022
2011	0.970	1.024	0.970	0.999	0.993
2012	1.013	0.906	1.009	1.003	0.917
Geomean	**0.999**	**1.023**	**0.999**	**1.000**	**1.022**
Growth (%)	**0.09**	**0.07**	**0.06**	**0.07**	**0.18**

Source: Results estimates
Note: 1981* indicates change from previous year; Geomean = Geometric Mean

4.2.2 Productivity changes over the years

Table 4.2 gives the productivity change estimates for the periods 1980-1990; 1991-2000 and 2001-2012 for the countries studied. The results indicate productivity change increased by 3.2%, 2.2% and 1.3% for the period 1980-1990, 1991-2000 and 2000-2012 respectively.

During the 1980s and 1990s, the growth in productivity is attributed to improved technical change. The technological change and technical efficiency change in the 1980s was 3% and 0.2% respectively, as presented in Figure 4.2 with pure efficiency and scale efficiency each improving by 0.1%. In the 1990s, the rate of technical change and efficiency change was 2.2%, with no variation in efficiency change, as presented in Figure 4.3. Pure efficiency declined by 0.1% and scale efficiency improved by 0.1%.

The improved productivity coincides with policy changes initiated by governments starting in the 1980s, as shown in Table 4.3. Most African output and input markets were controlled and regulated until the mid-1980s and beginning of the 1990s, when controls were dismantled thus allowing investments in the neglected areas (Kimuyu, 2005). The implementation of structural adjustment programs led to protective policies being abandoned (such as import substitution industrialisation which discriminated against agriculture in favour of manufacturing thus promoting agriculture growth (Trueblood & Coggins, 2003). The improved productivity growth rate was accredited to better macroeconomic conditions, declining conflicts, improved governance, liberalised markets and increased private sector involvement in the economy (Salami et al., 2010).

In the 2000s, productivity change and technical change was 1.3% and 1.7% respectively, with efficiency change and scale efficiency declining by 0.4% and 0.1% respectively. Technical change thus remained key to productivity growth in the 2000s, as illustrated in Figure 4.4. However, productivity change decline occurred in 2004, 2006, 2011 and 2012 because of declining technical efficiency and technical change. The declining technical efficiency change coincided with the prevailing unfavourable weather conditions experienced by most countries, implying farmers failed to correctly adjust inputs correctly to the prevailing conditions. The results therefore confirm that African agricultural productivity change improved in the 2000s because of technical progress demonstrating the importance of technical change in driving productivity growth.

Examining technical change and technical efficiency change reveals that average technical progress during the 1980s, 1990s and 2000s was 3%, 2.2% and 1.7% respectively. The average efficiency changes were 0.2%, 0% and -0.4% for the same periods, indicating a declining efficiency change in the 2000s. A further breakdown of efficiency change into pure technical efficiency and scale efficiency change components reveals that pure technical efficiency change improved by 0.1% in the 1980s and declined by 0.1% and 0.3% in the 1990s and 2000s respectively. Scale efficiency increased by 0.1% in both the 1980s and 1990s, and declined by 0.1% in the 2000s.

The results confirm that productivity growth in the 1980s was primarily driven by technical change coupled by growth in efficiency change and scale efficiency change. The results coincide with the findings of Thirtle, et al. (1993), which indicate that two factors drove productivity growth in the 1980s in many countries. First, through expanding the cropland area and two, by moving input resources (e.g. fertiliser and better crop varieties) into enterprises that were considered more profitable especially for those crops and products whose market prices had risen. The growth in scale efficiency implies that the countries' may have benefited by expanding the crop area. Some countries such as Zambia, Tanzania, Nigeria, Malawi and Kenya provided subsidies to farmers through providing inputs such as fertiliser and seed, hence increasing output.

The productivity growth in the 1980s and 1990s suggests that the agriculture sector seized the opportunity of the growing size of industry after the countries instituted reforms in the late 1980s to increase output. However, the lower level of productivity change in the 2000s and beyond indicates that Africa has not been able to sustain its agricultural productivity performance beyond the 2000s compared to the 1980s and 1990s. The slower growth since the 2000s, supports the findings of Alene (2010) which indicates that African agricultural productivity growth stagnated due to the regress in technical change and deteriorating technical efficiency change. The declining efficiency change especially in the post-reform years suggests the disappearance of the catch-up phenomenon which was more predominant in the pre-reform period.

Table 4.2 Malmquist index summary of annual means for different years

Year	Efficiency change	Technical change	Pure efficiency change	Scale efficiency change	Productivity change
1981	0.992	0.977	1.003	0.990	0.970
1982	0.995	0.971	0.988	1.007	0.966
1983	1.013	1.048	1.004	1.009	1.062
1984	1.015	0.974	1.022	0.994	0.989
1985	0.990	1.005	0.983	1.007	0.995
1986	1.010	1.019	1.006	1.004	1.029
1987	0.996	1.025	1.016	0.980	1.021
1988	0.999	1.048	0.987	1.012	1.046
1989	0.984	1.017	1.002	0.982	1.001
1990	1.023	1.246	0.996	1.027	1.275
Geomean	**1.002**	**1.030**	**1.001**	**1.001**	**1.032**
1991	0.987	1.015	0.981	1.006	1.002
1992	1.003	1.029	1.026	0.977	1.032
1993	1.007	0.974	0.978	1.030	0.981
1994	1.011	1.114	1.032	0.980	1.127
1995	0.987	1.082	0.983	1.004	1.068
1996	1.004	0.932	0.998	1.007	0.936
1997	0.994	1.038	0.987	1.007	1.033
1998	1.008	0.991	1.017	0.991	0.999
1999	1.011	0.996	1.014	0.997	1.008
2000	0.988	1.059	0.979	1.010	1.047
Geomean	**1.000**	**1.022**	**0.999**	**1.001**	**1.022**
2001	1.003	1.082	0.994	1.009	1.085
2002	1.000	1.049	0.997	1.003	1.049
2003	0.995	1.068	1.003	0.992	1.063
2004	0.990	0.964	0.990	1.001	0.955
2005	0.997	1.024	1.006	0.991	1.020
2006	0.987	0.987	0.988	0.998	0.974
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2008	0.981	1.030	0.979	1.002	1.010
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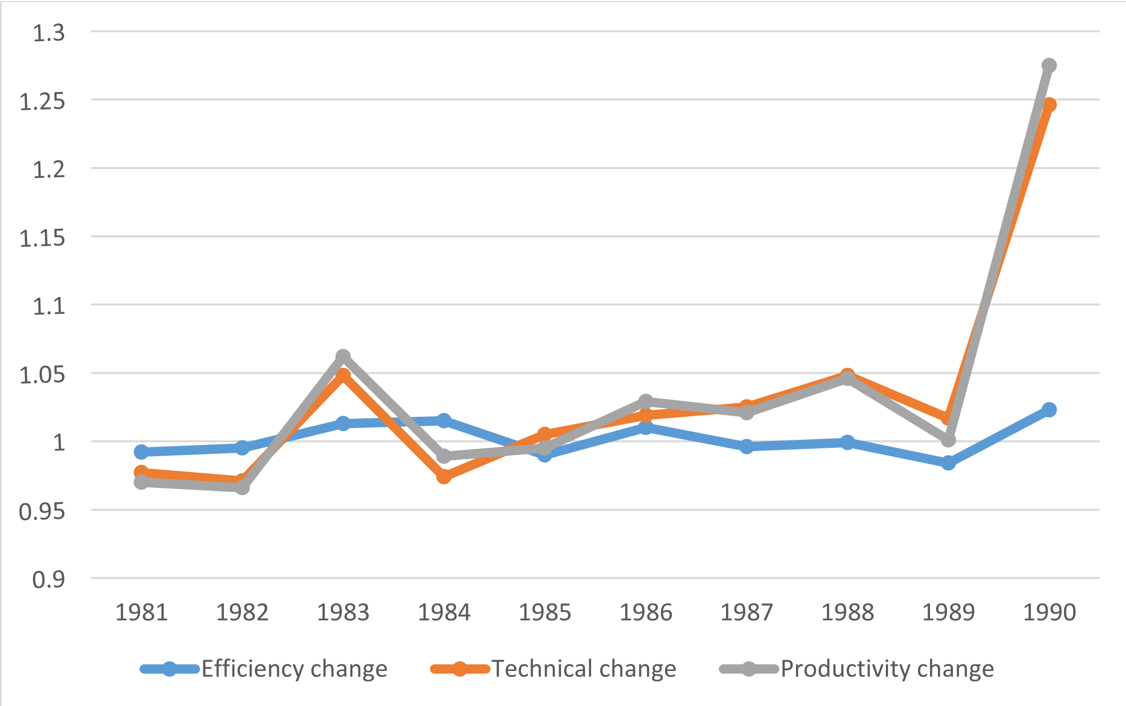
2010	1.009	1.013	1.007	1.002	1.022
2011	0.970	1.024	0.970	0.999	0.993
2012	1.013	0.906	1.009	1.003	0.917
Geomean	**0.996**	**1.017**	**0.997**	**0.999**	**1.013**

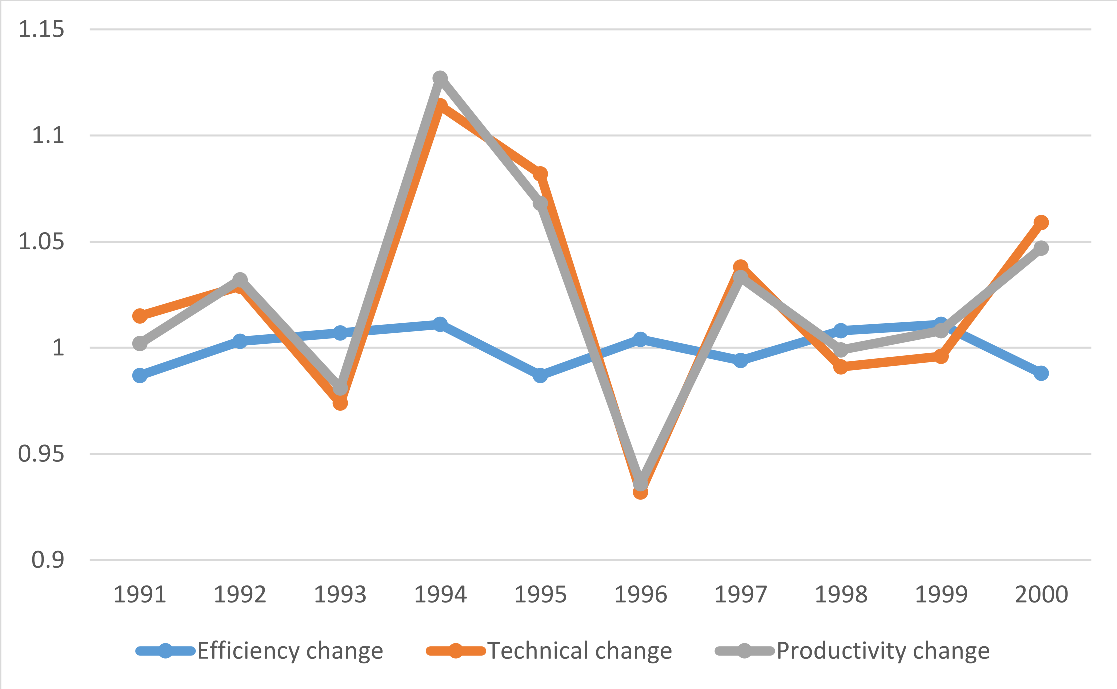
Source: Results estimates

In summary, African agricultural productivity change has improved over time although at a slow pace. The main productivity driving force is technical progress while the declining efficiency change implies a widening gap exists in African countries between the frontier technology and the best practise frontiers.



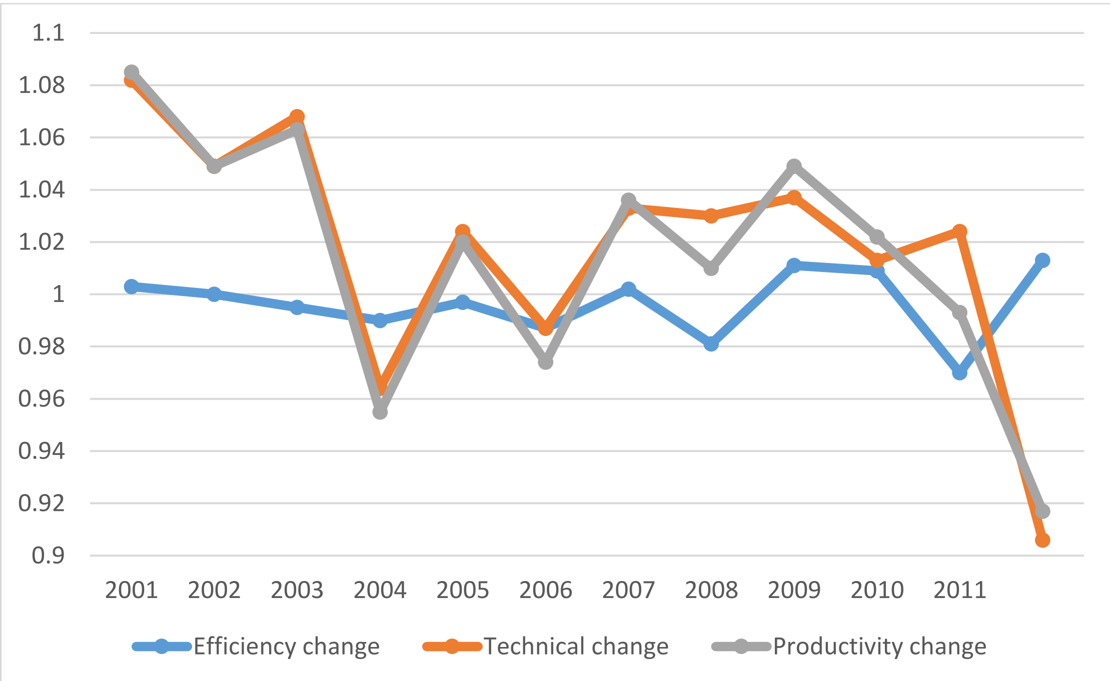
Source: Results estimates

Figure 4.2 Trends in productivity change, efficiency change and technical change of African agriculture, 1981-1990



Source: Results estimates

Figure 4.3 Trends in productivity change, efficiency change and technical change of African agriculture, 1991-2000



Source: Results estimates

Figure 4.4 Trends in productivity change, efficiency change and technical change of African agriculture, 2001-2012

Table 4.3 Summary of characteristics of agricultural systems, policy events and changes in selected countries

Country	Characteristics of the agricultural systems	Pre-reform period	Policy reforms
Algeria	➢ Main crops: wheat and barley, citrus fruit, vegetables, dates, figs, olives and grapes. ➢ Country dependent on food imports especially cereals ➢ Agriculture generates about 10% of the GDP and supports 25% of the population ➢ Arable land is very small with limited water ➢ Drought – 2000; floods – 2004, 2006, 2007 and 2008; earthquake in 2006; locusts in 2004	➢ All arable land controlled by state between 1961 and 1987	➢ State farms dismantled in 1987 and land allocated to smaller groups and individuals ➢ Market liberalisation ➢ National Plan for Agricultural Development launched in 2001
Angola	➢ Staple crops: cassava, maize, beans, potatoes, sweet potatoes and bananas ➢ Cash crops: coffee, tobacco, tea and cotton are grown for export ➢ Livestock: cattle and pigs ➢ Agriculture accounts for about 10% of the GDP ➢ Relies on food imports ➢ Endowed with fertile soils, adequate water and a good climate for agriculture ➢ Floods: 2009, 2010 and 2011	➢ 27 years of civil war that ended in 2002 ➢ No secure land rights ➢ Declined coffee exports in 1980s	➢ Capanda Agro-Industrial Zone initiated in 2002 and Market Oriented Small-holder Agriculture in 2007
Burkina Faso	➢ Food crops: sorghum, millet, rice, maize, cassava, cowpeas, sweet potatoes, beans and fruits (mangoes) ➢ Cash crops: cotton, cotton fiber, groundnuts, sesame, tobacco and sugarcane ➢ Livestock: goats, sheep, cattle, pigs, camels, chickens, ducks, horses, asses and guinea fowl ➢ Agriculture contributes about 30% of the GDP and employs over 80% of the population ➢ Livestock is the second most important source of foreign exchange after cotton ➢ Small scale farms of less than 5 ha ➢ Has tropical climate	➢ Drought in the early 1980s ➢ Suffers from chronic malnutrition and food insecurity ➢ Customary land tenure rules governed land transactions ➢ Suffered from several coups and political unrest in the 1980s	➢ Devaluation of the African Franc currency in 1994 ➢ Seed and fertiliser subsidies re-initiated in 2007 to boost food production ➢ Price support to cotton farmers since 2003 ➢ Price control of some food items initiated and import tariffs suspended after the 2008 food crisis ➢ Achieved allocation of 10% of the national budget to

Country	Characteristics of the agricultural systems	Pre-reform period	Policy reforms
		➢ Import substitution heavily protected by tariffs	agriculture in line with the Comprehensive Africa Agriculture Development Programme (CAADP) targets
Burundi	➢ Cash crops: tea, coffee, cotton and tobacco ➢ Food crops: maize, bananas, cassava, sorghum, rice and millet ➢ Livestock: cattle, goats, sheep and poultry ➢ Agriculture provides 90% of export revenues ➢ Agriculture predominantly small-scale subsistence farming ➢ Land highly fragmented, highly eroded and scarce ➢ Heavily relies on food imports and food aid ➢ Natural disasters include; droughts in 1999, 2005, 2008 & 2009; floods in 2007; storms in 2004 and epidemics in 1997, 1999 and 2000 ➢ Highly food insecure country	➢ Up to 1999 the economy was centrally planned ➢ Major economic problems due to civil war since 1991 ➢ Land governance system has no guarantee of tenure rights	➢ Arusha Peace Accord signed in the year 2000 ➢ Finalising of the Poverty Reduction Strategy Paper (PRSP) in 2006 and designing of the Priority Action Plan for 2007-2010 to guide its implementation; ➢ Decentralising of the economy.
Cameroun	➢ Cash crops: cocoa, maize, bananas, cotton, coffee, palm oil, rubber and tea. ➢ Food crops: cassava, beans, sorghum, vegetables, taro, groundnuts, potatoes and rice ➢ Over forty percent of total foreign exchange earnings ➢ Livestock: cattle, goats, sheep, poultry, camels, donkeys and horses ➢ Small-scale with slash and burn as the main farming practice ➢ Natural disasters include: drought in 1990; floods in 2007, 2008 and 2010; volcano in 1986 and 1999 and epidemics in 1992, 1993 and 2004	➢ Declining market prices of commodities such as petroleum, cocoa, coffee, and cotton in the mid-1980s leading to declining government revenues ➢ Experienced trade deficits ➢ Overvalued CFA Franc currency ➢ Recession in the mid-1980s up to early 2000s	➢ Economic reform programs initiated by the World Bank and IMF started in the late 1980s; ➢ Devaluation of CFA Franc by 50% in January 1994 ➢ Initiated the establishment of a Nationalized land registration system with valid registration certificates
Côte d'Ivoire	➢ Cash crops: cocoa, coffee, palm oil, rubber, cotton, coconut, copra and sugarcane	➢ Political and social turmoil in the 1990s ➢ Military coup d'état in December 1999	➢ Devaluing of the CFA Franc in 1994

Country	Characteristics of the agricultural systems	Pre-reform period	Policy reforms
	➢ Food crops: yams, manioc, rice, plantains, corn, sweet potatoes, peanuts, millet, sorghum eggplant, tomatoes, cabbage, okra, peppers, pineapples, shallots and rice ➢ Livestock: cattle, goats, sheep, swine and poultry, ➢ Fifty percent of its export earnings only twenty three percent of the land is farmed ➢ Highly intensive and efficiently organized ➢ Small-holders with numerous European owned plantations existing ➢ Natural disasters include; floods in 1989, 2007 and 2008 and epidemics in 1995, 2001 and 2008	➢ Declining commodity harvests such as of cocoa and coffee and poor market prices ➢ Economic recession in 2000	➢ Freezing of public sector investment since late 1999 ➢ Rural Land Law established in 1998
Egypt	➢ Cash crops: cotton and sugar cane ➢ Food crops: rice, wheat and maize; fruits (citrus, dates and grapes); potatoes and vegetables (leeks, garlic, melons, squashes, pulses, lettuce and tomatoes) ➢ Livestock: cattle, buffalo, goats, sheep and poultry ➢ Soil salinisation one of the most prominent soil problems ➢ Small farms with an average size of 0.84 ha ➢ Has the highest fertiliser use among the developing countries ➢ Floods – 1991, 1994 and 2010; earthquake – 1992 and 1993; landslide-2008; influenza outbreak – 2004 and 2009	➢ Market controlled economy ➢ Political instability and unrest since the 1980s ➢ Macroeconomic imbalance	➢ Market liberalisation started in the end of the 1970s ➢ El-Salam Canal erected in the 1990s for irrigation purposes ➢ Economic downturn after the 2011 political revolution
Gabon	➢ Cash-crops: coffee, cocoa, palm oil, sugar and rubber ➢ Food crops: maize, sweet potato, cassava, ground nuts, plantains, coco-yams and yams ➢ Livestock: cattle, goats, sheep and poultry ➢ Agriculture accounts for less than five percent of export revenues ➢ Subsistence farming is dominant ➢ Only five percent of the land is utilised for agriculture ➢ State is the major land owner since there is no land policy ➢ Food consumption is through imports ➢ Natural disasters include; floods in 1988 and epidemics in 1988, 1994, 1996, 2001 and 2007	➢ Political and economic unrest with two coup d'état attempts taking place in the 1990s	➢ Structural adjustment and trade liberalisation programmes initiated in the 1990s

Country	Characteristics of the agricultural systems	Pre-reform period	Policy reforms
Gambia	➢ Cash crops: groundnut, cotton and sesame ➢ Food crops: millet, maize, rice, sorghum ➢ Tropical vegetables and fruits such as chilies, green beans, aubergines, Asian vegetables, mangoes, papaya and limes are exported ➢ Livestock: cattle, sheep, goat, swine, rabbits, horses, donkeys, fowls, ducks and turkeys ➢ Agriculture accounts for 30% of the GDP and 70% of export earnings, mainly from sale of groundnut ➢ Sector supports up to 80% of the population ➢ Climate is largely semi-arid ➢ Natural disasters include; drought 1980; floods in 1996, 1999 and 2010; storms in 2003 and 2004 and epidemics in 1997	➢ Market was controlled up to 1990 in terms of product and inputs; ➢ Controlled exchange rates; ➢ Government subsidy of inputs especially fertiliser	➢ Market liberalisation; ➢ Improved exchange rates; ➢ Package Deal Programme that includes providing inputs such as fertiliser and seed reintroduced in the year 2000 ➢ Three land tenure systems which are freehold, leasehold, and customary
Ghana	➢ Cash crops: cocoa bean, cotton, coffee, palm oil, coconut, kola and rubber ➢ Food crops: maize, rice, cassava, yam, coco-yam, millet, sorghum, millet and plantains. Fruits and vegetables include: pineapples, citrus, cashew, pawpaw, mangoes, tomato, pepper, okra, eggplant, onion and Asian vegetables. ➢ Livestock: cattle, sheep, goats, pigs and chicken ➢ Agriculture contributes about 50% of revenue from exports and is a source of livelihood for up to 50% of the people ➢ Small-scale holdings with about 90% of the farms being less than 2 hectares in size predominant ➢ Natural disasters include; drought in 1983; floods in 1991, 1995, 1999 and 2001	➢ Food import substitution policy; ➢ Promotion of mechanisation ➢ Government controlled grain marketing board existed up to 1983 ➢ Provision of input subsidies ➢ Civil conflicts experienced ➢ Distorted market policies	➢ Economic recovery program initiated in the 1980s ➢ Trade liberalisation and foreign exchange controls lifted in the 1980s
Kenya	➢ Cash crops: tea, coffee, pyrethrum sisal, tobacco, cotton, flowers, sugarcane and bixa annatto ➢ Food crops: maize, wheat, rice, millet, potatoes, beans, peas, sorghum, sweet potatoes, cassava, bananas, oilseeds as french-beans, onions, cabbages, snow peas and fruits (avocados, mangoes and passion fruit) ➢ Livestock: cattle, goats, sheep, poultry, camels, donkeys and horses	➢ Structural reforms initiated in the 1980s with minimal proactive results ➢ Subsidies provided to farmers	➢ Liberalising of the maize market and cereal marketing through enacting of appropriate policy ➢ Fertiliser policy initiated ➢ Liberalisation of the markets

Country	Characteristics of the agricultural systems	Pre-reform period	Policy reforms
	➢ 80% of the population making a living from agriculture ➢ Small-scale farmers occupying holdings of less than 2 ha predominant ➢ Natural disasters include; droughts in 1991, 1994, 1997, 1999, 2004, 2005 and 2008; floods in 1997 and 2006 and epidemics in 1994	➢ Controlled markets ➢ Lack of appropriate agricultural policies ➢ Land policy program aimed at land consolidation and resettlement initiated in 1964 ➢ Post-election violence in 2007/08	➢ Adoption of improved varieties of maize ➢ Subsiding of maize inputs such as fertiliser and seed still prevalent ➢ Creation of export processing zones in 1990
Libya	➢ Cash crops: tobacco, vines, dates and olives ➢ Food crops: wheat, barley, maize, millet, potatoes, pulses, groundnuts, vegetables and fruits ➢ Livestock: cattle, goats, sheep, poultry and camels ➢ Agriculture contributes only about 8.2 percent of GDP ➢ Low work-force of about seventeen percent ➢ Most land is not arable ➢ Natural disasters included flooding in 1995	➢ Land purchasing loan schemes initiated by government ➢ Nationalising of the banks ➢ Political and civil unrest; ➢ Macroeconomic instability due to political unrest ➢ Declining commodity and oil prices	➢ Agriculture development plan for the period 1981-85 enacted ➢ Agricultural credit availed through the National Agricultural Bank ➢ Land and private sector reforms enacted
Madagascar	➢ Cash crops: coffee, vanilla, cloves and pepper; ➢ Food crops: rice, cassava, bananas, sweet potatoes, and maize ➢ Livestock: cattle, pigs, sheep, goats, chickens, ducks, geese and turkeys ➢ Agriculture accounts for thirty percent of GDP and employing about seventy-five percent of its work force ➢ Area has mountainous terrain coupled with extensive laterisation and inadequate rainfall ➢ Small-scale subsistence farmers dominant	➢ Markets controlled by the state ➢ Subsidising of food prices	➢ Market liberalisation started in 1983 ➢ Adopting of a flexible exchange rates ➢ Export Processing Zone created in 1989

Country	Characteristics of the agricultural systems	Pre-reform period	Policy reforms
	➢ Natural disasters include; drought in 1981, 1988 &2002; storms in 1994, 1997, 1999, 2000, 2002, 2004 and 2008		
Malawi	➢ Cash crops: coffee, cotton, tea, sugar and tobacco ➢ Food crops: maize, Cassava, sweet potatoes, rice, sorghum, groundnuts and pulses; ➢ Livestock: cattle, goats, sheep, pigs and poultry ➢ Agriculture contributes about 30% of the GDP with 90% of the country's revenue coming from exports ➢ 80% of the population is employed in the sector ➢ Small-holder farmers with land holdings of less than a hectare predominant ➢ Natural disasters include; droughts in 1979-1980, 1987, 1990, 1992, 2002 and 2007; floods in 1997, 2001, 2002 and 2007	➢ State controlled markets; ➢ Fertiliser subsidies to the farmers provided up to 1994 ➢ Existence of civil war and conflicts from 1975-1992	➢ Market for all produce and inputs liberalised except for maize after 1994 ➢ Liberalising of production and marketing of hybrid seed maize; ➢ Input support especially fertiliser subsidy for maize still provided up today ➢ Land reforms initiated in 1995 through multi-donor support
Mali	➢ Food crops: sorghum, millet, rice and maize; fruits, vegetables, henna and shea tree nut ➢ Cash crops: cotton, sugarcane and groundnuts ➢ Livestock: cattle, sheep, goats, pigs and poultry ➢ Agriculture provides about 45% of the GDP, 21% of exports revenue, and over 80% of the active labour force ➢ Land tenure governed by traditional and national law ➢ Natural disasters: locust invasion in 2004; drought in 2011 and floods in 2012	➢ Collapsing of the economy in 1985 ➢ Output market-controlled economy ➢ Civil rebellion between 1990 and 1996	➢ Land reforms undertaken in 1986 ➢ Agricultural Policy Act enacted in 2006 ➢ Liberalisation of the economy through diminished role of the state in crop marketing in 1987 ➢ Devalued CFA Franc currency in 1994 ➢ Coup in 2012
Mozambique	➢ Cash crops: tobacco, cotton, sesame, sugar, tea, coconut, cashew nuts, copra, tea and citrus fruits ➢ Food crops: maize, cassava, sorghum, millet, rice, beans, ground nut, banana, sweet potato and vegetables ➢ Livestock: cattle, goats, sheep, pigs and poultry	➢ Up to 1994 ➢ State controlled economy; ➢ Close to a decade of civil war (1975-1992);	➢ Economic and social rehabilitation program initiated after the civil war;

Country	Characteristics of the agricultural systems	Pre-reform period	Policy reforms
	➢ Accounts for forty percent of the GNP, sixty percent of export revenues and involves almost eighty percent of the active population; highly subsistence ➢ Rain-fed agriculture, traditional varieties, low use of fertiliser and pesticides; little or no mechanisation ➢ Natural disasters include; droughts in 1981, 1991, 2002, 2005 and 2007; floods in 1981, 1985, 2000 and 2001 and storm in 1994	➢ Economic instability started to occur in 1986; ➢ Civil war ended in 1993	➢ Market liberalisation and privatisation of government enterprises ➢ Improved tariff structure ➢ National Land Policy enacted in 1995
Niger	➢ Cash crops: cotton and groundnuts ➢ Food crop: pearl millet, sorghum, millet, wheat, cowpeas, onion, garlic, peppers, potatoes, cassava, rice, cowpeas, onions, garlic, peppers, potatoes and wheat ➢ Livestock: camels, cattle, sheep and goats ➢ Livestock provides about 15% of the GDP and supports 29% of the population ➢ Subsistence farming and very low mechanization predominant ➢ Natural disasters include; drought in 1983 and floods in 1988, 1994, 1998, 1999, 2001 and 2009 ➢ Arid, with two thirds of area considered desert	➢ Financial and economic problems up to 1994 ➢ Rainfall was generally poor between 1984 and 1990 ➢ Two coups in 1996 and 1999	➢ 1994 CFA Franc devaluation ➢ Decentralisation of services
Nigeria	➢ Cash crops: cocoa, citrus, cotton, groundnuts, palm oil, palm kernel, benniseed, and rubber; ➢ Food crops: maize, rice, plantains, cassava, cashew nuts, groundnuts, millet, sorghum, beans, yams, fruits and vegetables ➢ Livestock: cattle, goats, sheep, pigs, poultry, camels, donkeys and horses ➢ Agriculture accounts for thirty-two percent of the GDP and employs about seventy percent of the population. ➢ Natural disasters include; drought in 1983 and floods in 1988, 1994, 1998, 1999, 2001 and 2009	➢ Up to 1984 there was currency overvaluation ➢ Neglecting of agriculture in terms of public spending ➢ State-controlled markets ➢ Trade imbalance due to huge agricultural imports ➢ Ban on food imports adopted; ➢ Input support to the farmers such as fertiliser	➢ Structural adjustment program initiated in the 1990s ➢ Devaluing of the Naira currency ➢ Initiating of the Agricultural Development Projects (ADPs) ➢ Adaptive research especially on cassava initiated ➢ Existing Land Use Act of 1978 but with powers vested on state governors on land use decisions

Country	Characteristics of the agricultural systems	Pre-reform period	Policy reforms
		➢ Boko Haram crisis experienced in the late 2000s	➢ Lifting of ban on food imports
Rwanda	➢ Agriculture supports up to 91% of the population ➢ Food crops: maize, rice, plantains, cassava, beans, sweet potatoes, wheat and tefu ➢ Cash crops: coffee, tea, sugarcane, barley and green beans ➢ Livestock: cattle, goats, pigs, sheep and poultry ➢ Has fertile soils with average farm size being about 1 ha per family ➢ Natural disasters include; floods in 2007, 2008, 2011 and 2012	➢ Civil unrests such as the 1994 genocide ➢ State controlled markets	➢ Comprehensive Africa Agriculture Development Programme (CAADP) adopted in 2007 ➢ Agriculture sector investment plan initiated in 2009 ➢ Reconstruction of infrastructure after the civil war
South Africa	➢ Food crops: potatoes, maize, wheat, sorghum, ➢ Other crops: fruits (grapes, apples, pears, and peaches), sunflower seeds, barley, beans and soybeans ➢ The country is self-sufficient in food production and is a net food exporter of most food crops ➢ Drought in 1991 to 92; floods – 1996, 2005, 2008, 2009 and 2011; earthquake - 2005; influenza epidemic - 2009 ➢ Has a successful agricultural sector which is attributed to the strong political ➢ Agriculture is highly intensified	➢ Land was under the white settlers up to 1994 ➢ Highly regulated and subsidised ➢ Xenophobic attacks witnessed	➢ Deregulation of agricultural marketing and liberalisation of agricultural trade completed by the late 1990s ➢ Land redistribution programme started in 1994 ➢ Deregulation of the sector in 1980s ➢ Integrated Food Security Strategy adopted in 2002 ➢ Adopted the genetically modified crops since 1998
Sudan (Former)	➢ Cash crop: cotton and cottonseed ➢ Food crops: wheat, sorghum, millet, maize, rice, sesame, groundnuts, pulses, bananas, potatoes, vegetables and fruits ➢ Livestock: cattle, goats, sheep, poultry and camels ➢ Employs up to 80% of the population and contributes about 40% of the GDP ➢ Natural disasters include; droughts in 1983, 1987, 1990, 1991, 2000 and 2009 floods in 1988, 1998, 2003 and 2007	➢ Up to 1994 market interventionist policy existed leading to distorted markets ➢ Civil war and unrest	➢ Economic reforms initiated in the 1990s ➢ Currency devaluation; ➢ Liberalisation of domestic markets ➢ Since late 1980s land use became communally owned under customary land laws

Country	Characteristics of the agricultural systems	Pre-reform period	Policy reforms
Togo	➢ Cash crop: coffee, cocoa and cotton ➢ Food crops: maize, sorghum, pearl millet, rice, peanuts, beans, soy, yams and cassava ➢ Livestock: cattle, goats, sheep and poultry ➢ Contributes up to forty two percent of GDP ➢ Natural disasters include; drought in 1989; floods in 1994, 1995, 1998, 1999, 2007 and 2010	➢ Up to 1994 state-controlled markets	➢ Devaluing of the CFA Franc currency in 1994 ➢ Taxes on food crops abolished ➢ Land reform initiated in 1974
Tunisia	➢ Cash crops: olive oil, dates, citrus fruits, almonds and wine grapes ➢ Food crops: wheat, barley, potatoes and vegetables (tomatoes, peppers, artichokes, onions and sugar beets), almonds, apricots and melons ➢ Livestock: wattle, goats, sheep, poultry, camels, donkeys and horses ➢ Agriculture contributes about 15% of the country's GDP, employs about 20% of the people ➢ Country produces enough fruits, vegetables and dairy products to meet the demand of the population ➢ Labour-intensive agriculture characterised by low mechanisation, low levels of fertilisers and pesticides usage ➢ Majority land holdings are less than 20 ha ➢ Natural disasters include; drought in 1988, floods in 1982, 1986, 1990, 2003, 2007 and 2009 and insect infestation in 1988	➢ Up to 1986 state control markets ➢ Input subsidisation programs were common ➢ Price support programs in place ➢ Civil strife including the famous Tunisia revolution in 2010	➢ Joined the World Trade Organisation (WTO) in 1995 ➢ Agricultural credit availed to farmers ➢ Free-trade agreement with the EU initiated in the 2000
Uganda	➢ Food crops: maize, plantains, rice, cassava, sweet potato, millet, sorghum, maize, wheat, beans and groundnuts ➢ Cash crops: tea, coffee, cotton and tobacco ➢ Livestock: cattle, sheep and goats ➢ Floods – 2011; Marburg fever and Ebola outbreak – 2012; landslide – 2012	➢ Cash crop production collapsed at the end of the 1970s ➢ Political unrest and civil strife ➢ State-controlled economy ➢ Restricted capital flows	➢ Agricultural Sector Development Strategy and Investment Plan adopted in 2010 ➢ Modernization of Agriculture (PMA) implemented between 2001 and 2009

Country	Characteristics of the agricultural systems	Pre-reform period	Policy reforms
			➢ Liberalised exchange rates in the 1990 and easing of capital flows restrictions
Tanzania	➢ Cash crops: coffee, tea, pyrethrum, cotton, cashew nut, tobacco, sisal, cloves and horticultural crops ➢ Food crops: maize, millet, sorghum, millet, rice, wheat, beans, cassava, potatoes, bananas, fruits and vegetables ➢ Livestock: cattle, goats, sheep, chicken, turkeys and donkeys ➢ Agriculture provides about 27% of the country's GDP and employs many people ➢ Small-scale farming is dominant with average farm sizes of 0.9-3.0 hectares ➢ Natural disasters include; drought in 1984, 1988, 1991, 1996, 2003, 2004 and 2006 and floods in 1989, 1993 and 1990 ➢ Land tenure is based on right of occupancy and leasehold with no freehold system	➢ Up to 1985 state controlled markets ➢ Agriculture was communal based ➢ Economic down turn and stagnation ➢ War with neighbouring Uganda	➢ Economic recovery program initiated in the mid-1986; ➢ Devaluing of the shilling currency ➢ Liberalisation of the markets and removal of price controls ➢ Phasing out of commodity subsidies ➢ Launching of the Agriculture Sector Development Programme (ASDP) in 2006 ➢ Private investment in agriculture encouraged in 1983
Zambia	➢ Cash crops: maize, cotton, tobacco and sugarcane ➢ Food crops: maize, groundnuts, cassava, sweet potatoes and fruits ➢ Livestock: cattle, goats, sheep, pigs and poultry ➢ Agriculture provides 20% of the GDP and employs 70% of the population ➢ Mainly subsistence farming with high land fragmentation ➢ Natural disasters include; droughts in 1991, 1995 and 2005; floods in 1989, 1998, 2001, 2004, 2007 & 2009	➢ Up to 1991 the state controlled the markets ➢ Subsidies directed towards fertiliser support, transport and milling enterprises ➢ Emphasis was on maize farming	➢ Liberalising of the markets and putting marketing of maize under the Zambia Food Reserve Agency (FRA) ➢ Fertiliser Support Programme put in place in the year 2000; ➢ Customary tenure system and leasehold are the two forms of land allocation
Zimbabwe	➢ Food crops: maize, sorghum, pearl millet, finger millet, ground nuts, wheat, cow peas, bambara nuts and sweet potatoes	➢ Political and economic crisis since the 2000s	➢ Market reforms and deregulation started in 1991

Country	Characteristics of the agricultural systems	Pre-reform period	Policy reforms
	➢ Cash crops: tobacco, cotton, tea, coffee, sugarcane, soya bean, sunflower and horticultural products ➢ Livestock: cattle, poultry, pigs, sheep and goats ➢ Floods –2008, 2010 and 2011; influenza epidemic - 2009	➢ State controlled economy before 1991	➢ Economic Structural Adjustment Program (ESAP), adopted in 1991 ➢ Zimbabwe Agricultural Policy framework adopted in 1994 ➢ Fast-track land resettlement and redistribution programme started in 2000 and is on-going with tremendous negative impact on political and economic well-being of the country

Source: Adapted from Pratt & Yu (2008) and other sources

4.2.3 Comparison of productivity and its components across countries

The summary results of the MI index and its components for the countries are provided in Table 4.4. Productivity change varied across countries, although not considerably with the majority (twenty-three out of twenty-seven) of the countries experiencing positive productivity change, which is consistent with previous studies such as Alene (2010), Avila & Evenson (2010) and Pratt & Yu (2012).

Algeria experienced the highest productivity change of 5.6% due to technical change. Moreover, the country remained technically efficient over the 33-year sample period. Gabon, Rwanda and Uganda experienced negative productivity change of 32.8%, 0.9% and 0.9% respectively, with Angola, Gambia, Tanzania, Zambia and Zimbabwe experiencing negative efficiency growth rates of 1%, 1.7%, 0.6%, 1.2% and 1.2% respectively. Burundi's productivity change decline stems from declining technical efficiency and scale efficiency change. Rwanda and Uganda suffered from political conflict in the recent past. Conflicts are known to have severe impact on productivity due to displacement of people, in the process reducing their access to food, destroying infrastructure and causing livestock loss (Messer et al., 2001). Gabon's declining agricultural workforce and no or low changes in yields explains the negative productivity change due to declining technical change (Pratt & Yu, 2008). Gabon is largely a crude oil producer and exporter this accounting for 50% of its GDP and 80% of its exports making agriculture a minor contributor to GDP. Gabon remains a net food importer, which implies oil revenues are financing food imports to cater for the domestic food demand instead of depending on local production which may explain the country's low adoption of agricultural technologies (Sachs & Warner, 1995).

It is worth noting that countries recovering from war, most recently Mozambique, experienced a substantial increase in productivity due to efficiency change (Fuglie & Rada, 2013). Mozambique has shown improved productivity growth rate over recent times, implying that the post-recovery period led to a boost in the agricultural sector's output specifically due to increased investment in technology. Furthermore, countries such as Mozambique offer ideal conditions for agriculture with numerous sources of water, adequate rainfall and a good range of agricultural crops which can be grown. The country also offers cheap land which is available with 50-year leases, hence promoting large-scale farming by foreign companies. The effects of neighbouring countries can also have had an impact on agriculture - for example, due to political instability in Zimbabwe, farmers have been renting farms in Mozambique to grow crops such as tobacco and horticultural crops for export. Also, subsidised inputs such as fertiliser and seed from the surrounding countries, e.g., Malawi or Zambia, have ended up in the Mozambican markets making it easy for farmers to access cheaper inputs (Worldbank, 2006).

The mean change was 1.3%, indicating a positive shift in the frontier technology. In some countries, technical change contributes more to productivity change than in others. For example, Nigeria had a technical change of 3.3%, Libya 4.2% and Tunisia 3% suggesting that these countries operate closer to the frontier for a given level of technology. Although Nigeria has improved crop varieties, low fertiliser use (an average of 10–15 kg/ha) remains a major constraint to agricultural productivity growth since increased yield potential cannot be realised without a corresponding increase in fertiliser use (Phillip et al., 2009). Gabon, Niger, Rwanda and Uganda exhibited a decline in technical change of 2.1%, 1%, 17% and 2% due to low technology adoption levels (Akudugu et al., 2012; Lall & Pietrobelli, 2002). The declining productivity change in these countries is due to low technical change arising from exposure to periods of civil unrest, drought and macroeconomic mismanagement (Pratt & Yu, 2008).

From an examination of efficiency change, it is apparent that although many countries attained maximum efficiency in each period, the mean annual change of -0.4% implies deteriorating efficiency. This indicates a widening gap between the given country's technology and the frontier technology. Gambia, Togo, Tanzania, Zambia and Zimbabwe experienced declining efficiency change of 17%, 3%, 3%, 11% and 17%, respectively although they had positive productivity change attributed to technical change. From the declining efficiency change, it is evident that technology is not being used at optimal levels due to the slowing rate of catch up. The low degree of catch up may be attributed to country-specific institutional factors, domestic market environment and international trade policies as outlined in Table 4.3. For example, Tanzania and Zambia's fertiliser and maize subsidy programmes have led to the extension of maize growing even to areas that were not suitable for cultivation and which increased its vulnerability to drought, distorted prices, biased research focus and extension towards maize hence reducing efficiency even in other crops including those that had a comparative advantage over maize. Studies have shown that subsidised inputs crowd out the private sector deliveries, discourage investment in new private fertiliser sales networks, do not encourage sustainable fertiliser use, and lead to diversion and rent-seeking all of which do little to raise crop productivity (Crawford et al., 2006). Moreover, the political unrest in Zimbabwe since the 2000s is likely to have contributed to its declining efficiency.

Further decomposition of the efficiency change component into pure technical and scale efficiency changes indicates that pure technical efficiency declined in four countries (Angola, Tanzania, Zambia and Zimbabwe), with the highest decline experienced by Angola (1.1%). This decline in pure technical efficiency suggests that the countries fail to use inputs efficiently. Countries that still provide input subsidies to farmers such as Zambia and Tanzania have declining pure technical efficiency as shown from the results of this study. As noted by Banful (2011) subsidies do not provide incentive to use fertiliser efficiently hence affecting output. Scale efficiency however, did not seem to change in almost all the countries which implies that it contributed less to overall technical inefficiency than pure technical inefficiency. However, Gambia (-1.7%) and Mozambique (-0.3%) experienced scale efficiency regress, implying they failed to operate at sub-optimal scale size. Angola (0.1%), Burkina Faso (1%), Libya (0.4%), Togo (0.9%) and Zambia (0.1%) experienced an outward shift of scale efficiency, implying that the countries took advantage of optimising their scale of operations and hence increased scale efficiency. The results confirm existing findings that output growth in some countries has been attributed to expanding the cropping area by large-scale farmers with little or no change of output per unit area of land (Pauw & Thurlow, 2011; Benson et al., 2014).

Table 4.4 Malmquist summary of country means

Country	Efficiency change	Technical change	Pure efficiency	Scale efficiency	Productivity change
Algeria	1.000	1.056	1.000	1.000	1.056
Angola	0.990	1.014	0.989	1.001	1.004
Burkina Faso	1.010	1.032	1.000	1.010	1.042
Burundi	1.000	1.003	1.000	1.000	1.003
Cameroun	1.000	1.027	1.000	1.000	1.027
Côte d'Ivoire	1.000	1.004	1.000	1.000	1.004
Egypt	1.000	1.055	1.000	1.000	1.055
Gabon	1.000	0.962	1.000	1.000	0.962
Gambia	0.983	1.025	1.000	0.983	1.007
Ghana	1.006	1.019	1.006	1.000	1.025
Kenya	1.000	1.026	1.000	1.000	1.026
Libya	1.004	1.049	1.000	1.004	1.053
Madagascar	1.000	1.028	1.000	1.000	1.028
Malawi	1.005	1.019	1.005	1.000	1.024
Mali	1.000	1.032	1.000	1.000	1.032
Mozambique	1.002	1.015	1.004	0.997	1.017
Niger	1.000	1.024	1.000	1.000	1.024
Nigeria	1.000	1.043	1.000	1.000	1.043
Rwanda	1.000	0.991	1.000	1.000	0.991
South Africa	1.000	1.038	1.000	1.000	1.038
Sudan (former)	1.000	1.037	1.000	1.000	1.037
Togo	1.009	0.999	1.000	1.009	1.008
Tunisia	1.000	1.050	1.000	1.000	1.050
Uganda	1.000	0.991	1.000	1.000	0.991
Tanzania	0.994	1.024	0.994	1.000	1.018
Zambia	0.988	1.029	0.987	1.001	1.017
Zimbabwe	0.988	1.028	0.988	1.000	1.016

Source: Results estimates

4.2.4 Regional frontiers and technology gap change among regions

Table 4.5 provides the results for the regions grouped into Eastern Africa (Burundi, Kenya, Madagascar, Malawi, Mozambique, Rwanda, Uganda and Tanzania), Western Africa (Burkina Faso, Côte d'Ivoire, Gambia, Ghana, Mali, Niger, Nigeria and Togo), Southern Africa (South Africa, Zambia and Zimbabwe), Central Africa (Angola, Cameroun and Gabon) and Northern Africa (Algeria, Egypt, Libya, Tunisia and Sudan (Former)) based on their geographical location. The northern region had the highest productivity change of 6.4% due to a positive shift in technical change of 6.4%, followed by southern region (productivity change of 3.7%). These regions had a positive shift in technical change, technical efficiency change and scale efficiency change of 3.1%, 0.6% and 0.6% respectively, while pure efficiency change declined by

9.8%. The western region had productivity change of 2.2% with a positive shift in technical change of 2.3%, while efficiency change, pure efficiency change and scale efficiency declined by 0.1%, 3.1% and 0.1% respectively. The eastern region had a productivity change of 1.2%, with a positive shift in technical change and efficiency change of 1.1% and 0.1% respectively while pure efficiency change declined by 0.8%. The Central region had a productivity regress of 0.2% due to a fall in technical change of 0.2% while efficiency change, pure technical and scale efficiency remained constant.

In the Eastern Africa region, Tanzania had the highest productivity change of 3.4%, while there were declines in Rwanda (-1.3%) and Uganda (-1.2 %). In the Central African region, Cameroun had the highest productivity change of 3.9% while Gabon experienced a regress of 4.9%. In the North Africa region, Sudan (Former) and Tunisia experienced the highest productivity change of 6.2% and 8.5% respectively. In the Southern Africa region, Zambia had the highest productivity change of 4%. In the Western Africa region, Burkina Faso (4.7%) had the highest productivity change while Côte d’Ivoire (0.7%) experienced a decline.

Table 4.5 Regional analysis of productivity and its components among selected countries

African Region	Country	Efficiency Change	Technical change	Pure Efficiency	Scale efficiency	Productivity change
Eastern	Burundi	1.000	1.005	1.000	1.000	1.005
	Kenya	1.000	1.021	1.000	1.000	1.021
	Madagascar	1.000	1.024	1.000	1.000	1.024
	Malawi	1.004	1.018	0.944	1.001	1.023
	Mozambique	1.000	1.014	0.995	1.000	1.014
	Rwanda	1.000	0.987	1.000	1.000	0.987
	Uganda	1.000	0.988	1.000	1.000	0.988
	Tanzania	1.000	1.034	0.995	1.000	1.034
	Geomean	1.001	1.011	0.992	1.000	1.012
Central	Angola	1.000	1.006	1.000	1.000	1.006
	Cameroun	1.000	1.039	1.000	1.000	1.039
	Gabon	1.000	0.951	1.000	1.000	0.951
	Geomean	1.000	0.998	1.000	1.000	0.998
Northern	Algeria	1.000	1.060	1.000	1.000	1.060
	Egypt	1.000	1.056	1.000	1.000	1.056
	Libya	1.000	1.056	1.000	1.000	1.056
	Sudan (Former)	1.000	1.062	1.000	1.000	1.062
	Tunisia	1.000	1.085	1.000	1.000	1.085
	Geomean	1.000	1.064	1.000	1.000	1.064
Southern	South Africa	1.000	1.035	1.000	1.000	1.035
	Zambia	1.018	1.021	0.733	1.018	1.040
	Zimbabwe	1.000	1.038	1.000	1.000	1.038
	Geomean	1.006	1.031	0.902	1.006	1.037
Western	Burkina Faso	1.000	1.047	0.999	1.000	1.047
	Côte d’Ivoire	1.000	0.993	1.000	1.000	0.993
	Gambia	0.992	1.012	0.830	0.992	1.004
	Ghana	1.000	1.007	0.977	1.000	1.007
	Mali	1.000	1.040	1.000	1.000	1.040
	Niger	1.000	1.031	1.000	1.000	1.031
	Nigeria	1.000	1.040	1.000	1.000	1.040
	Togo	1.000	1.015	0.960	1.000	1.015
	Geomean	0.999	1.023	0.969	0.999	1.022

Source: Results estimates

Examining the technology gap change (TGC) in Table 4.6 which indicates the change in technology leadership between period t and t+1, Tunisia had the highest productivity change ratio of 1.033 and Ghana at 0.982 was the lowest. A ratio greater than 1 implies that the gap in a country’s production technology has improved over time, while a value less than 1 implies a deteriorating gap. The low productivity change ratio for Ghana is attributed to its agricultural sector having a low level of technology adoption (Akudugu et al., 2012; Lall & Pietrobelli, 2002). Overall, the results indicate only a slight improvement in technical change, efficiency change and productivity change while only pure technical efficiency had greatly improved over time among the regions.

Table 4.6 Technology gap ratios among selected countries

Country	**Efficiency Change**	**Technical change**	**Pure Efficiency**	**Scale efficiency**	**Productivity change**
Algeria	1.000	1.004	1.000	1.000	1.004
Angola	1.010	0.992	1.011	0.999	1.002
Burkina Faso	0.990	1.014	0.999	0.990	1.005
Burundi	1.000	1.002	1.000	1.000	1.002
Cameroun	1.000	1.012	1.000	1.000	1.012
Côte d’Ivoire	1.000	0.989	1.000	1.000	0.989
Egypt	1.000	1.001	1.000	1.000	1.001
Gabon	1.000	0.988	1.000	1.000	0.988
Gambia	1.009	0.988	0.830	1.009	0.997
Ghana	0.994	0.988	0.971	1.000	0.982
Kenya	1.000	0.995	1.000	1.000	0.995
Libya	0.996	1.007	1.000	0.996	1.003
Madagascar	1.000	0.996	1.000	1.000	0.996
Malawi	0.999	1.000	0.940	1.001	0.999
Mali	1.000	1.008	1.000	1.000	1.008
Mozambique	0.998	0.999	0.991	1.003	0.997
Niger	1.000	1.007	1.000	1.000	1.007
Nigeria	1.000	0.997	1.000	1.000	0.997
Rwanda	1.000	0.996	1.000	1.000	0.996
South Africa	1.000	0.997	1.000	1.000	0.997
Sudan (Former)	1.000	1.024	1.000	1.000	1.024
Togo	0.991	1.016	0.960	0.991	1.007
Tunisia	1.000	1.033	1.000	1.000	1.033
Uganda	1.000	0.997	1.000	1.000	0.997
Tanzania	1.006	1.010	1.001	1.000	1.016
Zambia	1.031	0.993	0.743	1.017	1.023
Zimbabwe	1.012	1.009	1.012	1.000	1.021
Ratios	1.001	1.002	0.978	1.000	1.003

Source: Results estimates

4.2.5 Hypothesis testing

To test the null-hypothesis that the distribution of the pooled mean productivity change and its components and that of the regions is the same across the categories of groups of countries, a Kruskal Wallis Test was carried out. The following hypotheses were tested:

Hypothesis 1: H_0 = The distribution of efficiency change is the same across the different categories of countries

H_1 = The distribution of efficiency change is different across the different categories of countries

Hypothesis 2: H_0 = The distribution of technical change is the same across the different categories of countries

H_1 = The distribution of technical change is different across the different categories of countries

Hypothesis 3: H_0 = The distribution of pure efficiency is the same across the different categories of countries

H_1 = The distribution of pure efficiency is different across the different categories of countries

Hypothesis 4: H_0 = The distribution of scale efficiency is the same across the different categories of countries

H_1 = The distribution of scale efficiency is different across the different categories of countries

Hypothesis 5: H_0 = The distribution of productivity change is the same across the different categories of countries

H_1 = The distribution of productivity change is different across the different categories of countries

The null-hypothesis was retained, given the distribution of productivity change and its components was found to be the same across the groups of countries as observed in Table 4.7.

Table 4.7 Hypothesis testing using Kruskal Wallis Test of the means

Null hypothesis	P- value	Decision
Pooled efficiency change = Regional efficiency change	0.973	Accepted
Pooled technical change = Regional technical change	0.723	Accepted
Pooled pure efficiency = Regional pure efficiency	0.058	Accepted
Pooled scale efficiency = Regional scale efficiency	0.500	Accepted
Pooled productivity change = Regional productivity change	0.539	Accepted

Source: Results estimates

4.2.6 Summary and conclusion

The mean productivity change and technical change were 2.2% and 2.3% respectively; efficiency change and pure technical efficiency declined by 0.1% each while scale efficiency remained constant.

The results indicate that productivity grew in the 1980s due to growth in technical efficiency of 0.2%, while technical change progressed by 3%. Both pure technical efficiency and scale efficiency change improved by 0.1%. The positive shift in scale efficiency suggests an expansion of the land area under farming and possible reallocation of resources such as seed and fertiliser into crops and products that were more profitable - a phenomenon that was common in many countries and which contributed towards overall productivity growth (Thirtle et al., 1993).

In the 1990s, productivity growth improved with an average change of 2.2%. The average change of technical change was 2.2%, while efficiency change remained constant. A decline of 0.1% change in pure technical efficiency was realised while scale efficiency change improved by 0.1%. This implies that the driving force of productivity growth in the 1990s was technical change.

In the 2000s - a period when most countries initiated reforms - productivity grew by 1.3% while technical change was 1.7%. The efficiency change decreased by 0.4% due to declining pure technical efficiency change (-0.3%) and scale efficiency change (-0.1%). The results indicate that technical progress had become more important in driving productivity growth in the 2000s, although the declining efficiency change suggests that African countries failed to catch up in the post-reform years.

Thus, the results indicate that technical change remains the driving force of productivity gain in the twenty-seven countries, while efficiency change has contributed little towards productivity change over the years. Initiatives undertaken by the countries such as adopting new technologies, use of modern inputs such as fertiliser and improved seed varieties and minimisation of input or output market inefficiencies may have contributed to productivity growth (Pratt & Yu, 2008).

Examining the regional productivity, the Northern Africa region had the highest productivity mean of 6.4%, followed by the Southern Africa region (3.7%) while the Central African region had a decline of 0.2%. The mean technology gap ratio indicate that productivity change, technical change and technical efficiency change had a positive shift while pure technical efficiency seems to have declined over time.

4.3 RESULTS OF PRODUCTIVITY CHANGE WHEN INCORPORATING BAD OUTPUT

In this section, the MLI and its components are presented for the twenty-seven countries covering the period from 1980 to 2012.

4.3.1 Annual mean productivity change and its components

Table 4.8 presents productivity change estimates for five models. Model 1 provides the results of the Malmquist Index with good outputs. Models 2, 3 and 4 provide results for the MLI when considering CO_2, CH_4 and N_2O emissions respectively. Model 5 provides the MLI estimates when all three bad outputs are considered. The MI is included to compare the results with MLI when bad outputs are included in the analysis.

The average productivity change for models 2, 3, 4 and 5 was 0.7%, -1.4%, -1.6% and -0.4%, respectively. These estimates indicate that if factor inputs for each respective country were kept fixed, on average, agriculture output could increase or decrease by 0.7%, -1.4%, -1.6% and -0.4% per year. Considering models 2, 3, 4 and 5, it is observed that the number of countries exhibiting increasing MLI were thirteen, eleven, eight and nine, respectively. The MLI results are given in Table 4.8. The results reveal that for models 2, 3, 4 and 5 the technical change on average improved by 0.8%,

-1.3%, -1.5%, and -0.3%, respectively, while efficiency change declined by 0.1% for all the four models. A close examination of the decomposed components of efficiency change (i.e. pure technical efficiency and scale efficiency change) indicates that pure technical efficiency contributed to the declining efficiency change (-7.2%, -7.2%, -7.3% and -5.4% for models 2, 3, 4 and 5 respectively).

Countries such as Cameroun, Uganda, Tanzania and Zimbabwe had high productivity when bad output was incorporated in all the models due to the positive shift in technical change, while Algeria, Côte d'Ivoire, Egypt, Nigeria and Zambia had negative productivity change when bad output was considered in all the models which suggests that these countries' lack the initiative in adopting technology to curb emissions. Tanzania's Vision 2025 for instance spells out the country's agenda for agricultural growth and managing of resources as a key driver to sustainable agriculture (URT, 2001., 2003). The Tanzanian agriculture sector development strategy promotes conservation agriculture to make land more productive. Several countries' programmes initiated by their governments such as reforestation, agroforestry, protecting the water catchments and improved land husbandry have helped curb land degrading activities (Shetto & Lyimo, 2001). The top rice producing countries in Africa such as Egypt, Nigeria, Madagascar and Côte d'Ivoire recorded a decline in productivity change when accounting for CH_4 emissions, which suggests high paddy field CH_4 emissions.

Livestock remains the largest contributor of N_2O emissions which emanate from paddocks, ranges and pastures (Hickman et al., 2011). Thus, countries such as Sudan (Former) with large livestock herds had declining productivity change when including N_2O emissions in the analysis due to high emissions from the livestock sector. Libya, South Africa, Tunisia, Algeria, Egypt and Angola with known high global CO_2 emission also had declining productivity change when accounting for CO_2 emissions.

Table 4.8 Malmquist index (MI) and Malmquist Luenberger index (MLI) and their components across countries

Country	Model 1: MI					Model 2: MLI (CO_2 emissions)					Model 3: MLI (CH_4 emissions)				
	effch	tech	pech	sech	proch	effch	tech	pech	sech	proch	effch	tech	pech	sech	proch
Algeria	1.000	1.056	1.000	1.000	1.056	1.000	0.999	1.000	1.000	0.999	1.000	0.983	1.000	1.000	0.983
Angola	0.990	1.014	0.989	1.001	1.004	0.991	0.978	0.819	1.000	0.969	0.991	1.014	0.823	1.000	1.004
Burkina Faso	1.010	1.032	1.000	1.010	1.042	1.002	1.044	0.878	1.002	1.046	1.002	1.060	0.875	1.002	1.063
Burundi	1.000	1.003	1.000	1.000	1.003	1.000	0.981	1.000	1.000	0.981	1.000	1.000	1.000	1.000	1.000
Cameroun	1.000	1.027	1.000	1.000	1.027	1.000	1.058	0.936	1.000	1.058	1.000	1.015	0.929	1.000	1.015
Côte d'Ivoire	1.000	1.004	1.000	1.000	1.004	1.000	0.993	1.000	1.000	0.993	1.000	0.980	1.000	1.000	0.980
Egypt	1.000	1.055	1.000	1.000	1.055	1.000	0.992	1.000	1.000	0.992	1.000	0.941	1.000	1.000	0.941
Gabon	1.000	0.962	1.000	1.000	0.962	1.000	1.017	1.000	1.000	1.017	1.000	1.002	1.000	1.000	1.002
Gambia	0.983	1.025	1.000	0.983	1.007	0.998	1.002	0.707	0.998	1.000	0.998	1.001	0.697	0.998	1.000
Ghana	1.006	1.019	1.006	1.000	1.025	1.000	1.001	0.974	1.000	1.001	1.000	1.003	0.983	1.000	1.003
Kenya	1.000	1.026	1.000	1.000	1.026	1.000	0.915	0.995	1.000	0.915	1.000	1.010	0.992	1.000	1.010
Libya	1.004	1.049	1.000	1.004	1.053	1.002	1.002	0.998	1.002	1.004	1.003	0.982	0.997	1.003	0.985
Madagascar	1.000	1.028	1.000	1.000	1.028	1.000	1.097	1.000	1.000	1.097	1.000	0.936	1.000	1.000	0.936
Malawi	1.005	1.019	1.005	1.000	1.024	1.002	0.990	0.872	1.001	0.992	1.005	1.002	0.888	1.001	1.006
Mali	1.000	1.032	1.000	1.000	1.032	1.000	1.002	1.000	1.000	1.002	1.000	0.844	1.000	1.000	0.844
Mozambique	1.002	1.015	1.004	0.997	1.017	0.995	1.002	0.783	1.001	0.997	0.996	0.985	0.783	1.001	0.980
Niger	1.000	1.024	1.000	1.000	1.024	1.000	1.051	1.000	1.000	1.051	1.000	0.950	1.000	1.000	0.950
Nigeria	1.000	1.043	1.000	1.000	1.043	1.000	0.969	1.000	1.000	0.969	1.000	0.974	1.000	1.000	0.974
Rwanda	1.000	0.991	1.000	1.000	0.991	1.000	1.080	1.000	1.000	1.080	1.000	1.006	1.000	1.000	1.006
South Africa	1.000	1.038	1.000	1.000	1.038	1.000	0.963	1.000	1.000	0.963	1.000	0.946	1.000	1.000	0.946
Sudan (former)	1.000	1.037	1.000	1.000	1.037	1.000	1.008	1.000	1.000	1.008	1.000	0.990	1.000	1.000	0.990
Togo	1.009	0.999	1.000	1.009	1.008	1.004	0.988	0.880	1.004	0.992	1.005	0.988	0.886	1.005	0.993
Tunisia	1.000	1.050	1.000	1.000	1.050	1.000	0.999	1.000	1.000	0.999	1.000	1.000	1.000	1.000	1.000
Uganda	1.000	0.991	1.000	1.000	0.991	1.000	1.039	1.000	1.000	1.039	1.000	1.006	1.000	1.000	1.006
Tanzania	0.994	1.024	0.994	1.000	1.018	0.991	1.021	0.836	1.000	1.011	0.991	1.024	0.831	1.000	1.014
Zambia	0.988	1.029	0.987	1.001	1.017	0.995	1.002	0.703	1.000	0.997	0.996	1.002	0.710	1.001	0.997
Zimbabwe	0.988	1.028	0.988	1.000	1.016	0.991	1.032	0.814	1.000	1.023	0.991	1.029	0.807	1.000	1.020
Geomean	**0.999**	**1.023**	**0.999**	**1.000**	**1.022**	**0.999**	**1.008**	**0.928**	**1.000**	**1.007**	**0.999**	**0.987**	**0.928**	**1.000**	**0.986**

Table 4.8 Continued

Country	Model 4: MLI (N_2O emissions)					Model 5: MLI (CO_2, CH_4 & N_2O)				
	effch	**tech**	**pech**	**sech**	**proch**	**effch**	**tech**	**pech**	**sech**	**proch**
Algeria	1.000	0.981	1.000	1.000	0.981	1.000	0.990	1.000	1.000	0.990
Angola	0.991	0.957	0.817	1.000	0.949	0.993	0.975	0.858	1.000	0.968
Burkina Faso	1.002	0.977	0.877	1.002	0.979	1.002	1.030	0.903	1.002	1.031
Burundi	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Cameroun	1.000	1.022	0.934	1.000	1.022	1.000	1.046	0.944	1.000	1.046
Côte d'Ivoire	1.000	0.985	1.000	1.000	0.985	1.000	0.985	1.000	1.000	0.985
Egypt	1.000	0.971	1.000	1.000	0.971	1.000	0.978	1.000	1.000	0.978
Gabon	1.000	1.001	1.000	1.000	1.001	1.000	0.997	1.000	1.000	0.997
Gambia	0.998	1.002	0.722	0.998	0.999	0.999	1.001	0.791	0.999	1.000
Ghana	1.000	0.998	0.969	1.000	0.998	1.000	0.999	0.986	1.000	0.999
Kenya	1.000	1.081	0.994	1.000	1.081	1.000	1.009	0.996	1.000	1.009
Libya	1.002	0.982	0.998	1.002	0.983	1.001	0.989	0.999	1.001	0.991
Madagascar	1.000	0.859	1.000	1.000	0.859	1.000	1.062	1.000	1.000	1.062
Malawi	1.000	1.008	0.859	1.001	1.008	1.004	1.002	0.913	1.001	1.006
Mali	1.000	0.966	1.000	1.000	0.966	1.000	0.910	1.000	1.000	0.910
Mozambique	0.995	1.008	0.781	1.001	1.003	0.996	0.983	0.829	1.000	0.980
Niger	1.000	0.882	1.000	1.000	0.882	1.000	0.949	1.000	1.000	0.949
Nigeria	1.000	0.944	1.000	1.000	0.944	1.000	0.937	1.000	1.001	0.937
Rwanda	1.000	0.992	1.000	1.000	0.992	1.000	0.999	1.000	1.000	0.999
South Africa	1.000	0.954	1.000	1.000	0.954	1.000	0.967	1.000	1.000	0.967
Sudan (former)	1.000	0.988	1.000	1.000	0.988	1.000	0.991	1.000	1.000	0.991
Togo	1.003	0.987	0.873	1.003	0.990	1.004	1.044	0.907	1.000	1.048
Tunisia	1.000	1.000	1.000	1.000	1.000	1.000	0.997	1.000	1.000	0.997
Uganda	1.000	1.005	1.000	1.000	1.005	1.000	1.004	1.000	1.000	1.004
Tanzania	0.991	1.026	0.838	1.000	1.017	0.993	1.019	0.870	1.000	1.012
Zambia	0.996	1.001	0.702	1.000	0.997	0.998	1.001	0.773	1.004	0.999
Zimbabwe	0.992	1.037	0.817	1.000	1.029	0.993	1.070	0.847	1.000	1.062
Geomean	**0.999**	**0.985**	**0.927**	**1.000**	**0.984**	**0.999**	**0.997**	**0.946**	**1.000**	**0.996**

Source: Results estimates

Note: effch = efficiency change; tech = technical change; pech = pure technical efficiency change; sech = scale efficiency change; and proch = productivity change.

4.3.2 Comparing productivity change of the Malmquist Index and Malmquist Luenberger Index models

This section examines the MI and the MLI models of productivity change trends for the countries under study. Table 4.9 presents the difference in productivity change between MI and MLI models which indicate how productivity changes when including CO_2, CH_4 or N_2O in the production function. A positive (negative) change between the MI and MLI estimates indicates a decline (increase) in productivity or increase (decrease) in the bad outputs. The productivity change difference involves subtracting productivity change of bad output from productivity change of good output.

In comparing Model 1 with the other models, productivity is shown to decline by 1.5%, 3.8% and 3.5% when accounting for CO_2, N_2O and CH_4 emissions respectively. This implies that productivity change when good output only is factored in the analysis was greater than when bad output was included in the analysis. Kenya, South Africa, Nigeria, Egypt, Algeria, Tunisia and Libya had the highest productivity change decline when factoring CO_2 into the analysis, with a gap of 11.1%, 7.5%, 7.4%, 6.3%, 5.7%, 5.1% and 4.9%, respectively. The results reaffirm the findings of Canadell et al. (2009) that countries such as South Africa and Libya remain top CO_2 emitters in Africa. Rwanda, Madagascar, Gabon and Uganda had the highest productivity change increase by 8.9%, 6.9%, 5.5% and 4.8% respectively when considering CO_2 emissions, which suggests that these countries are low CO_2 emitters.

Comparing Model 1 and Model 3, 4 and 5, similar outcomes were apparent only in respect of the productivity change gap. Only five countries had positive productivity change when including N_2O and CH_4 emissions in the analysis, with Madagascar and Niger showing the highest productivity decline of 16.9% and 14.2% respectively in the presence of N_2O emissions. Regarding CH_4 emissions, Mali and Egypt had the highest productivity decline of 18.8% and 11.4% respectively. When all the three bad outputs were included in the analysis, Mali and Nigeria had the highest productivity declines of 12.2% and 10.6% respectively.

4.3.3 Comparing technical change and efficiency change between Malmquist Index and Malmquist Luenberger Index models

Examining Model 1 and Model 2, technical change reveals a positive gap in many of the countries when including CO_2 with a decline of 1.5%. The results thus imply a negative shift in production possibilities frontier towards producing more bad output and less good output. However, the efficiency change did not seem to change, although pure technical efficiency declined by 6.6% in the presence of CO_2 emissions, which suggests the possibility of a negative relationship between increased bad output and efficient resource use. Comparing Model 1 with models 3 and 4, technical change showed a positive gap of 3.7% and 3.5% respectively, efficiency change remained constant while pure technical efficiency change declined by 6.6% in each of the models respectively.

The results suggest that increased CH_4 and N_2O contributed to declining technical change and pure efficiency change. Comparing Model 1 and Model 5, the technical change indicated a positive gap of 2.5% with no change in efficiency change while pure technical efficiency declined by 5%. Egypt, Libya, Mali, Nigeria, South Africa and Tunisia had a large decline in productivity and its components due to increasing bad outputs. Technical change declined when factoring bad output in the analysis which suggests that countries may not be adopting technologies that could reduce greenhouse gases.

Livestock production systems (including producing and processing of feeds) and ruminants' enteric fermentation are identified as the two primary sources of agriculture greenhouse gases which contribute immensely to the sector's emissions by approximately 45 and 39 percent respectively (Gerber et al., 2013). Ideally, interventions to reduce greenhouse gases should target on technologies and measures that can enhance livestock productivity.

Table 4.9 Comparing mean productivity change between Malmquist index (MI) and Malmquist Luenberger index (MLI) models

Country	Model 1 (good output) versus Model 2 (with CO_2 emissions)					Model 1 (good output) versus Model 3 (with N_2O emissions)					Model 1 (good output) versus Model 4 (with CH_4 emissions)				
	effch	tech	pech	sech	proch	effch	tech	pech	sech	proch	effch	tech	pech	sech	proch
Algeria	0.000	0.057	0.000	0.000	0.057	0.000	0.075	0.000	0.000	0.075	0.000	0.073	0.000	0.000	0.073
Angola	-0.001	0.036	0.170	0.001	0.035	-0.001	0.057	0.172	0.001	0.055	-0.001	0.000	0.166	0.001	0.000
Burkina Faso	0.008	-0.012	0.122	0.008	-0.004	0.008	0.055	0.123	0.008	0.063	0.008	-0.028	0.125	0.008	-0.021
Burundi	0.000	0.022	0.000	0.000	0.022	0.000	0.003	0.000	0.000	0.003	0.000	0.003	0.000	0.000	0.003
Cameroun	0.000	-0.031	0.064	0.000	-0.031	0.000	0.005	0.066	0.000	0.005	0.000	0.012	0.071	0.000	0.012
Côte d'Ivoire	0.000	0.011	0.000	0.000	0.011	0.000	0.019	0.000	0.000	0.019	0.000	0.024	0.000	0.000	0.024
Egypt	0.000	0.063	0.000	0.000	0.063	0.000	0.084	0.000	0.000	0.084	0.000	0.114	0.000	0.000	0.114
Gabon	0.000	-0.055	0.000	0.000	-0.055	0.000	-0.039	0.000	0.000	-0.039	0.000	-0.040	0.000	0.000	-0.040
Gambia	-0.015	0.023	0.293	-0.015	0.007	-0.015	0.023	0.278	-0.015	0.008	-0.015	0.024	0.303	-0.015	0.007
Ghana	0.006	0.018	0.032	0.000	0.024	0.006	0.021	0.037	0.000	0.027	0.006	0.016	0.023	0.000	0.022
Kenya	0.000	0.111	0.005	0.000	0.111	0.000	-0.055	0.006	0.000	-0.055	0.000	0.016	0.008	0.000	0.016
Libya	0.002	0.047	0.002	0.002	0.049	0.002	0.067	0.002	0.002	0.070	0.001	0.067	0.003	0.001	0.068
Madagascar	0.000	-0.069	0.000	0.000	-0.069	0.000	0.169	0.000	0.000	0.169	0.000	0.092	0.000	0.000	0.092
Malawi	0.003	0.029	0.133	-0.001	0.032	0.005	0.011	0.146	-0.001	0.016	0.000	0.017	0.117	-0.001	0.018
Mali	0.000	0.030	0.000	0.000	0.030	0.000	0.066	0.000	0.000	0.066	0.000	0.188	0.000	0.000	0.188
Mozambique	0.007	0.013	0.221	-0.004	0.020	0.007	0.007	0.223	-0.004	0.014	0.006	0.030	0.221	-0.004	0.037
Niger	0.000	-0.027	0.000	0.000	-0.027	0.000	0.142	0.000	0.000	0.142	0.000	0.074	0.000	0.000	0.074
Nigeria	0.000	0.074	0.000	0.000	0.074	0.000	0.099	0.000	0.000	0.099	0.000	0.069	0.000	0.000	0.069
Rwanda	0.000	-0.089	0.000	0.000	-0.089	0.000	-0.001	0.000	0.000	-0.001	0.000	-0.015	0.000	0.000	-0.015
South Africa	0.000	0.075	0.000	0.000	0.075	0.000	0.084	0.000	0.000	0.084	0.000	0.092	0.000	0.000	0.092
Sudan (former)	0.000	0.029	0.000	0.000	0.029	0.000	0.049	0.000	0.000	0.049	0.000	0.047	0.000	0.000	0.047
Togo	0.005	0.011	0.120	0.005	0.016	0.006	0.012	0.127	0.006	0.018	0.004	0.011	0.114	0.004	0.015
Tunisia	0.000	0.051	0.000	0.000	0.051	0.000	0.050	0.000	0.000	0.050	0.000	0.050	0.000	0.000	0.050
Uganda	0.000	-0.048	0.000	0.000	-0.048	0.000	-0.014	0.000	0.000	-0.014	0.000	-0.015	0.000	0.000	-0.015
Tanzania	0.003	0.003	0.158	0.000	0.007	0.003	-0.002	0.156	0.000	0.001	0.003	0.000	0.163	0.000	0.004
Zambia	-0.007	0.027	0.284	0.001	0.020	-0.008	0.028	0.285	0.001	0.020	-0.008	0.027	0.277	0.000	0.020
Zimbabwe	-0.003	-0.004	0.174	0.000	-0.007	-0.004	-0.009	0.171	0.000	-0.013	-0.003	-0.001	0.181	0.000	-0.004
Average	**0.000**	**0.015**	**0.066**	**0.000**	**0.015**	**0.000**	**0.037**	**0.066**	**0.000**	**0.038**	**0.000**	**0.035**	**0.066**	**0.000**	**0.035**

Table 4.9 Continued

Country	Model 1 (good output) versus Model 5 (with CO_2, CH_4 and N_2O emissions)				
	effch	tech	pech	sech	proch
Algeria	0.000	0.066	0.000	0.000	0.066
Angola	-0.003	0.039	0.131	0.001	0.036
Burkina Faso	0.008	0.002	0.097	0.008	0.011
Burundi	0.000	0.003	0.000	0.000	0.003
Cameroun	0.000	-0.019	0.056	0.000	-0.019
Côte d'Ivoire	0.000	0.019	0.000	0.000	0.019
Egypt	0.000	0.077	0.000	0.000	0.077
Gabon	0.000	-0.035	0.000	0.000	-0.035
Gambia	-0.016	0.024	0.209	-0.016	0.007
Ghana	0.006	0.020	0.020	0.000	0.026
Kenya	0.000	0.017	0.004	0.000	0.017
Libya	0.003	0.060	0.001	0.003	0.062
Madagascar	0.000	-0.034	0.000	0.000	-0.034
Malawi	0.001	0.017	0.092	-0.001	0.018
Mali	0.000	0.122	0.000	0.000	0.122
Mozambique	0.006	0.032	0.175	-0.003	0.037
Niger	0.000	0.075	0.000	0.000	0.075
Nigeria	0.000	0.106	0.000	-0.001	0.106
Rwanda	0.000	-0.008	0.000	0.000	-0.008
South Africa	0.000	0.071	0.000	0.000	0.071
Sudan (former)	0.000	0.046	0.000	0.000	0.046
Togo	0.005	-0.045	0.093	0.009	-0.040
Tunisia	0.000	0.053	0.000	0.000	0.053
Uganda	0.000	-0.013	0.000	0.000	-0.013
Tanzania	0.001	0.005	0.124	0.000	0.006
Zambia	-0.010	0.028	0.214	-0.003	0.018
Zimbabwe	-0.005	-0.042	0.141	0.000	-0.046
Average	**0.000**	**0.025**	**0.050**	**0.000**	**0.025**

Source: Results estimates

4.3.4 Hypothesis testing

Table 4.10 provides the results of a Kruskal Wallis Test for all the models to test the null hypotheses whether the distribution of MI and MLI scores and their components differ across the categories of groups.

The null hypothesis that the distribution of productivity and technical change is the same for MI and MLI models for the countries was rejected at the 5% significance level. However, the null hypothesis for pure technical efficiency, scale efficiency and efficiency change for MI and MLI models was not rejected at the 5% significance level. This implies that the comparative growth rates of good and bad outputs determine the corresponding growth in productivity with technical change being the determining factor.

There is therefore sufficient evidence to suggest that the two indexes are significantly different, which implies that excluding undesirable outputs in any productivity estimation would yield biased results in productivity change, efficiency change and technical change. The statistical significance difference between the MI and MLI estimates of productivity change implies that the MI may not be a reasonable substitute for the MLI when incorporating bad outputs in the estimation.

Table 4.10 Hypothesis testing using Kruskal Wallis Test of the means

	Model 2 (with CO_2 emissions)		**Model 3 (with N_2O emissions)**		**Model 4 (with CH_4 emissions)**		**Model 5 (with CO_2, CH_4 and N_2O emissions)**	
Null hypothesis	**p-value**	**Decision**	**p-value**	**Decision**	**p-value**	**Decision**	**p-value**	**Decision**
ML=M	0.019	Reject	0.000	Reject	0.000	Reject	0.001	Reject
MLPech=MPech	0.001	Reject	0.001	Reject	0.001	Reject	0.001	Reject
MLTech=MTech	0.026	Reject	0.000	Reject	0.000	Reject	0.001	Reject
MLEffch=MEffch	0.548	Accept	0.535	Accept	0.602	Accept	0.561	Accept
MLSech=MSech	0.908	Accept	0.908	Accept	0.858	Accept	0.734	Accept

Source: Results estimates

Note: MLI= Malmquist luenberger index; MLPECH = Malmquist luenberger pure technical efficiency; MLTECH = Malmquist luenberger technical Change; MLEFFCH = Malmquist luenberger efficiency change; MLSECH = Malmquist luenberger scale efficiency; M=Malmquist index; MPECH = Malmquist pure technical efficiency; MTECH = Malmquist technical change; MEFFCH = Malmquist efficiency change and MSECH = Malmquist scale efficiency.

4.3.5 Productivity change and its components regional frontiers

Table 4.11 provides the results for the regions grouped into Eastern Africa (Burundi, Kenya, Madagascar, Malawi, Mozambique, Rwanda, Uganda and Tanzania), Western Africa (Burkina Faso, Côte d'Ivoire, Gambia, Ghana, Mali, Niger, Nigeria and Togo), Southern Africa (South Africa, Zambia and Zimbabwe), Central Africa (Angola, Cameroun and Gabon) and Northern Africa (Algeria, Egypt, Libya, Tunisia and Sudan (Former)) based on their geographical location. The mean productivity change when accounting for CO_2 emissions was -0.3%, 5.1%, -2%, -1.5% and -2.1% for the Eastern, Central, Northern, Southern and Western Africa regions respectively. The mean productivity change in the presence of CH_4 emissions was 0.2%, -2.5%, -2.3%, -1.1% and -3.4% for the Eastern, Central, Northern, Southern and Western Africa regions, respectively. The mean productivity change when accounting for N_2O emissions was 1.1%, -2.7%, -1.7%, 0% and -1.9% for the Eastern, Central, Northern, Southern and Western Africa regions respectively. The mean productivity change when accounting for three (CO_2, N_2O and CH_4) emissions was 0.9%, -0.6%, -2.1%, -1.6% and -2.6% for the Eastern, Central, Northern, Southern and Western Africa regions respectively. The results thus indicate productivity change in most of the regions in the presence of emissions.

An examination of the Eastern Africa region, Kenya and Tanzania exhibited higher productivity change for all the models due to technical change, while Mozambique experienced a decline in productivity change for all the models due to declining technical and pure technical efficiency change. In the Central African region, there was a decline in productivity change for all the models except for Angola which experienced a positive productivity change when including CO_2 emissions in the analysis. In the Northern Africa region, Libya and Tunisia had positive productivity change, while the rest of the countries had a declining change. In the Southern region, only Zambia had positive productivity change for all the models. In the West African region, only Ghana and Burkina Faso had a positive productivity change when accounting for CO_2 and the three (CO_2, N_2O and CH_4) emissions respectively.

Table 4.11 Regional frontiers in the presence of emissions

African Region	Country	CO_2 emissions effch	tech	pech	sech	proch	CH_4 emissions effch	tech	pech	sech	proch
Eastern	Burundi	1.000	0.979	1.000	1.000	0.979	1.000	1.000	1.000	1.000	1.000
	Kenya	1.000	1.044	1.000	1.000	1.044	1.000	1.056	1.000	1.000	1.056
	Madagascar	1.000	1.013	1.000	1.000	1.013	1.000	0.935	1.000	1.000	0.935
	Malawi	1.005	1.002	0.942	1.000	1.007	1.004	1.004	0.959	1.000	1.008
	Mozambique	1.000	0.896	0.974	1.000	0.896	1.000	0.988	0.969	1.000	0.988
	Rwanda	1.000	0.992	1.000	1.000	0.992	1.000	0.971	1.000	1.000	0.971
	Uganda	1.000	1.041	1.000	1.000	1.041	1.000	1.006	1.000	1.000	1.006
	Tanzania	1.000	1.011	0.979	1.000	1.011	1.000	1.061	0.979	1.000	1.061
	Geomean	**1.001**	**0.996**	**0.987**	**1.000**	**0.997**	**1.000**	**1.002**	**0.988**	**1.000**	**1.002**
Central	Angola	1.000	1.160	1.000	1.000	1.160	1.000	0.979	1.000	1.000	0.979
	Cameroun	1.000	1.002	1.000	1.000	1.002	1.000	0.947	1.000	1.000	0.947
	Gabon	1.000	1.000	1.000	1.000	1.000	1.000	0.999	1.000	1.000	0.999
	Geomean	**1.000**	**1.051**	**1.000**	**1.000**	**1.051**	**1.000**	**0.975**	**1.000**	**1.000**	**0.975**
Northern	Algeria	1.000	0.996	1.000	1.000	0.996	1.000	1.015	1.000	1.000	1.015
	Egypt	1.000	0.992	1.000	1.000	0.992	1.000	0.941	1.000	1.000	0.941
	Libya	1.000	1.001	1.000	1.000	1.001	1.000	1.001	1.000	1.000	1.001
	Sudan (Former)	1.000	0.914	1.000	1.000	0.914	1.000	0.933	1.000	1.000	0.933
	Tunisia	1.000	1.001	1.000	1.000	1.001	1.000	1.001	1.000	1.000	1.001
	Geomean	**1.000**	**0.980**	**1.000**	**1.000**	**0.980**	**1.000**	**0.977**	**1.000**	**1.000**	**0.977**
Southern	South Africa	1.000	0.991	1.000	1.000	0.991	1.000	0.958	1.000	1.000	0.958
	Zambia	1.006	1.021	0.823	1.006	1.027	1.006	1.002	0.817	1.006	1.008
	Zimbabwe	1.000	0.940	1.000	1.000	0.940	1.000	1.000	1.000	1.000	1.000
	Geomean	**1.002**	**0.984**	**0.937**	**1.002**	**0.985**	**1.002**	**0.987**	**0.935**	**1.002**	**0.989**
Western	Burkina Faso	1.000	0.951	0.993	1.000	0.951	1.000	0.921	0.993	1.000	0.921
	Côte d’Ivoire	1.000	0.986	1.000	1.000	0.986	1.000	1.000	1.000	1.000	1.000
	Gambia	0.999	0.994	0.803	0.999	0.992	0.999	0.986	0.792	0.999	0.985
	Ghana	1.000	1.004	0.991	1.000	1.004	1.000	0.953	0.997	1.000	0.953
	Mali	1.000	0.959	1.000	1.000	0.959	1.000	0.916	1.000	1.000	0.916
	Niger	1.000	0.976	1.000	1.000	0.976	1.000	0.954	1.000	1.000	0.954
	Nigeria	1.000	0.944	1.000	1.000	0.944	1.000	0.999	1.000	1.000	0.999
	Togo	1.000	1.022	0.952	1.000	1.022	1.000	1.005	0.957	1.000	1.005
	Geomean	**1.000**	**0.979**	**0.965**	**1.000**	**0.979**	**1.000**	**0.966**	**0.965**	**1.000**	**0.966**

Table 4.11 continued

African Region	Country	CO_2, N_2O and CH_4 emissions effch	tech	pech	sech	proch	N_2O emissions effch	tech	pech	sech	proch
Eastern	Burundi	1.000	1.000	1.000	1.000	1.000	1.000	0.999	1.000	1.000	0.999
	Kenya	1.000	1.050	1.000	1.000	1.050	1.000	1.048	1.000	1.000	1.048
	Madagascar	1.000	1.036	1.000	1.000	1.036	1.000	0.952	1.000	1.000	0.952
	Malawi	1.003	1.003	0.968	1.000	1.006	1.006	1.001	0.936	1.000	1.007
	Mozambique	1.000	0.953	0.975	1.000	0.953	1.000	0.999	0.969	1.000	0.999
	Rwanda	1.000	0.977	1.000	1.000	0.977	1.000	1.005	1.000	1.000	1.005
	Uganda	1.000	1.004	1.000	1.000	1.004	1.000	1.005	1.000	1.000	1.005
	Tanzania	1.000	1.049	0.984	1.000	1.049	1.000	1.075	0.979	1.000	1.075
	Geomean	**1.000**	**1.009**	**0.991**	**1.000**	**1.009**	**1.001**	**1.010**	**0.985**	**1.000**	**1.011**
Central	Angola	1.000	1.025	1.000	1.000	1.025	1.000	0.976	1.000	1.000	0.976
	Cameroun	1.000	0.960	1.000	1.000	0.960	1.000	0.944	1.000	1.000	0.944
	Gabon	1.000	0.999	1.000	1.000	0.999	1.000	1.000	1.000	1.000	1.000
	Geomean	**1.000**	**0.994**	**1.000**	**1.000**	**0.994**	**1.000**	**0.973**	**1.000**	**1.000**	**0.973**
Northern	Algeria	1.000	0.979	1.000	1.000	0.979	1.000	1.017	1.000	1.000	1.017
	Egypt	1.000	0.978	1.000	1.000	0.978	1.000	0.971	1.000	1.000	0.971
	Libya	1.000	1.001	1.000	1.000	1.001	1.000	1.003	1.000	1.000	1.003
	Sudan (Former)	1.000	0.936	1.000	1.000	0.936	1.000	0.925	1.000	1.000	0.925
	Tunisia	1.000	1.000	1.000	1.000	1.000	1.000	1.001	1.000	1.000	1.001
	Geomean	**1.000**	**0.979**	**1.000**	**1.000**	**0.979**	**1.000**	**0.983**	**1.000**	**1.000**	**0.983**
Southern	South Africa	1.000	0.972	1.000	1.000	0.972	1.000	0.961	1.000	1.000	0.961
	Zambia	1.005	1.036	0.860	1.005	1.041	1.006	1.035	0.811	1.006	1.042
	Zimbabwe	1.000	0.943	1.000	1.000	0.943	1.000	1.000	1.000	1.000	1.000
	Geomean	**1.002**	**0.983**	**0.951**	**1.002**	**0.984**	**1.002**	**0.998**	**0.932**	**1.002**	**1.000**
Western	Burkina Faso	1.000	1.004	0.995	1.000	1.004	1.000	0.980	0.993	1.000	0.980
	Côte d'Ivoire	1.000	0.999	1.000	1.000	0.999	1.000	1.000	1.000	1.000	1.000
	Gambia	0.999	0.989	0.869	0.999	0.988	0.999	0.980	0.819	0.999	0.979
	Ghana	1.000	0.968	0.997	1.000	0.968	1.000	0.967	0.986	1.000	0.967
	Mali	1.000	0.887	1.000	1.000	0.887	1.000	0.942	1.000	1.000	0.942
	Niger	1.000	0.954	1.000	1.000	0.954	1.000	0.979	1.000	1.000	0.979
	Nigeria	1.000	0.999	1.000	1.000	0.999	1.000	0.999	1.000	1.000	0.999
	Togo	1.000	0.999	0.965	1.000	0.999	1.000	1.002	0.948	1.000	1.002
	Geomean	**1.000**	**0.974**	**0.977**	**1.000**	**0.974**	**1.000**	**0.981**	**0.966**	**1.000**	**0.981**

Source: Results estimates

An examination of the technology gap change (TGC) as shown in Table 4.12 indicates the technology change leadership between period t and period t+1. A ratio of more than 1 implies that the gap in the production technology of the country has improved over time and a value less than 1 implies a deteriorating gap. Angola had the highest productivity ratio of 1.197 due to a positive shift in technical change and pure technical efficiency change when factoring in CO_2 emissions. Mali had the highest productivity ratio of 1.085, mainly due to a positive shift in technical change in the presence of CH_4 emissions. Niger had the highest productivity ratio of 1.110 due to a positive shift in technical change in the presence of N_2O emissions while Nigeria had the highest productivity ratio of 1.067 due to a positive shift in technical change in the presence of the three (CO_2, CH_4 and N_2O) emissions.

Generally, the results indicate only a slight improvement in technical change, efficiency and productivity change in most countries while pure technical efficiency had greatly improved over time among the regions. Mozambique had the lowest productivity ratio of 0.899 due to a negative shift in technical change although pure technical efficiency change improved when factoring CO_2 emissions. Burkina Faso had the lowest productivity ratio of 0.866 due to a negative shift in technical change and scale efficiency when accounting for CH_4 emissions. Cameroun had the lowest productivity ratio of 0.923 due to a negative shift in technical change when including N_2O emissions while Zimbabwe had the lowest productivity ratio of 0.888 due to a negative shift in technical change when accounting for three (CO_2, CH_4 and N_2O) emissions.

Overall, the results indicate only a slight improvement in technical change, efficiency and productivity change in most countries while pure technical efficiency exhibited considerable improvement over time among the regions.

Table 4.12 Technology gap change in the presence of emissions

	CO_2 emissions					CH_4 emissions					N_2O emissions				
Country	**effch**	**tech**	**pech**	**sech**	**proch**	**effch**	**tech**	**pech**	**sech**	**proch**	**effch**	**tech**	**pech**	**sech**	**proch**
Algeria	1.000	0.997	1.000	1.000	0.997	1.000	1.033	1.000	1.000	1.033	1.000	1.037	1.000	1.000	1.037
Angola	1.009	1.186	1.221	1.000	1.197	1.009	0.966	1.215	1.000	0.975	1.009	1.020	1.224	1.000	1.028
Burkina Faso	0.998	0.911	1.131	0.998	0.909	0.998	0.869	1.135	0.998	0.866	0.998	1.003	1.132	0.998	1.001
Burundi	1.000	0.998	1.000	1.000	0.998	1.000	1.000	1.000	1.000	1.000	1.000	0.999	1.000	1.000	0.999
Cameroon	1.000	0.947	1.068	1.000	0.947	1.000	0.933	1.076	1.000	0.933	1.000	0.923	1.071	1.000	0.923
Côte d'Ivoire	1.000	0.992	1.000	1.000	0.992	1.000	1.020	1.000	1.000	1.020	1.000	1.015	1.000	1.000	1.015
Egypt	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Gabon	1.000	0.984	1.000	1.000	0.984	1.000	0.997	1.000	1.000	0.997	1.000	0.999	1.000	1.000	0.999
Gambia	1.001	0.992	1.135	1.001	0.992	1.001	0.985	1.136	1.001	0.985	1.001	0.978	1.135	1.001	0.980
Ghana	1.000	1.003	1.017	1.000	1.003	1.000	0.950	1.014	1.000	0.950	1.000	0.969	1.018	1.000	0.969
Kenya	1.000	1.141	1.005	1.000	1.141	1.000	1.045	1.008	1.000	1.045	1.000	0.970	1.006	1.000	0.970
Libya	0.998	0.999	1.002	0.998	0.997	0.997	1.019	1.003	0.997	1.016	0.998	1.021	1.002	0.998	1.020
Madagascar	1.000	0.924	1.000	1.000	0.924	1.000	0.999	1.000	1.000	0.999	1.000	1.108	1.000	1.000	1.108
Malawi	1.003	1.012	1.080	0.999	1.016	0.999	1.002	1.080	0.999	1.002	1.006	0.993	1.090	0.999	0.999
Mali	1.000	0.957	1.000	1.000	0.957	1.000	1.085	1.000	1.000	1.085	1.000	0.975	1.000	1.000	0.975
Mozambique	1.005	0.895	1.244	0.999	0.899	1.004	1.003	1.237	0.999	1.008	1.005	0.991	1.240	0.999	0.996
Niger	1.000	0.928	1.000	1.000	0.928	1.000	1.005	1.000	1.000	1.005	1.000	1.110	1.000	1.000	1.110
Nigeria	1.000	0.974	1.000	1.000	0.974	1.000	1.026	1.000	1.000	1.026	1.000	1.059	1.000	1.000	1.059
Rwanda	1.000	0.918	1.000	1.000	0.918	1.000	0.965	1.000	1.000	0.965	1.000	1.013	1.000	1.000	1.013
South Africa	1.000	1.029	1.000	1.000	1.029	1.000	1.013	1.000	1.000	1.013	1.000	1.007	1.000	1.000	1.007
Sudan (former)	1.000	0.907	1.000	1.000	0.907	1.000	0.942	1.000	1.000	0.942	1.000	0.936	1.000	1.000	0.936
Togo	0.996	1.034	1.082	0.996	1.030	0.995	1.018	1.080	0.995	1.013	0.997	1.015	1.086	0.997	1.012
Tunisia	1.000	1.002	1.000	1.000	1.002	1.000	1.001	1.000	1.000	1.001	1.000	1.001	1.000	1.000	1.001
Uganda	1.000	1.002	1.000	1.000	1.002	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Tanzania	1.009	0.991	1.171	1.000	1.000	1.009	1.037	1.178	1.000	1.047	1.009	1.048	1.169	1.000	1.057
Zambia	1.011	1.019	1.170	1.006	1.030	1.010	1.000	1.151	1.005	1.011	1.010	1.034	1.155	1.006	1.045
Zimbabwe	1.009	0.911	1.229	1.000	0.919	1.009	0.972	1.239	1.000	0.980	1.008	0.964	1.224	1.000	0.972

Table 4.12 continued

Country	CO_2, N_2O and CH_4 emissions effch	techch	pech	sech	proch
Algeria	1.000	0.989	1.000	1.000	0.989
Angola	1.007	1.052	1.166	1.000	1.059
Burkina Faso	0.998	0.975	1.101	0.998	0.974
Burundi	1.000	1.000	1.000	1.000	1.000
Cameroon	1.000	0.918	1.059	1.000	0.918
Côte d'Ivoire	1.000	1.015	1.000	1.000	1.015
Egypt	1.000	1.000	1.000	1.000	1.000
Gabon	1.000	1.002	1.000	1.000	1.002
Gambia	1.000	0.988	1.098	1.000	0.988
Ghana	1.000	0.969	1.012	1.000	0.969
Kenya	1.000	1.041	1.004	1.000	1.041
Libya	0.999	1.012	1.001	0.999	1.010
Madagascar	1.000	0.976	1.000	1.000	0.976
Malawi	0.999	1.001	1.060	0.999	1.000
Mali	1.000	0.975	1.000	1.000	0.975
Mozambique	1.004	0.970	1.176	1.000	0.973
Niger	1.000	1.005	1.000	1.000	1.005
Nigeria	1.000	1.067	1.000	0.999	1.067
Rwanda	1.000	0.978	1.000	1.000	0.978
South Africa	1.000	1.005	1.000	1.000	1.005
Sudan (former)	1.000	0.944	1.000	1.000	0.944
Togo	0.996	0.957	1.063	1.000	0.954
Tunisia	1.000	1.003	1.000	1.000	1.003
Uganda	1.000	1.000	1.000	1.000	1.000
Tanzania	1.007	1.030	1.131	1.000	1.037
Zambia	1.007	1.034	1.113	1.001	1.042
Zimbabwe	1.007	0.881	1.181	1.000	0.888

Source: Results estimates

4.3.6 Summary implications and conclusion

By employing the MLI both good and bad outputs are incorporated (in this case CO_2, CH_4 and N_2O) in the measurement of productivity change of African agriculture and its components.

The results suggest African countries are not performing well in reducing the GHG emissions, mainly CH_4 and N_2O. The results also indicate that when including bad output in the models, productivity change and its components of efficiency change and technical change was considerably lower. Thus, the results do not reflect the true productivity levels since overestimating productivity change occurs when not accounting for bad output in the analysis. When factoring CH_4 and N_2O emissions, productivity change was markedly lower than when including CO_2 in the analysis, implying that CH_4 and N_2O reduced agricultural productivity.

The overall policy implications of this study therefore centre on the need to promote strategies that will help reallocate resources from producing bad outputs to producing good outputs. Thus, policies that encourage efficient use of manure and fertiliser would clearly benefit farmers. For example, educating farmers on the need to efficiently store and manage manure and use the correct quantity of synthetic fertilisers, will help improve manure and fertiliser use and thus assist in recovery and recycling of nutrients. Efficient use of energy such as cutting down on fossil fuel use and adopting cleaner energy (e.g. solar) can contribute towards mitigating greenhouse gases in agriculture. Also, adopting technologies and measures that enhance crop and livestock productivity such as improved crop varieties and livestock breeds could also help reduce GHG emissions. Policies that encourage efficient use of water in rice farming are also relevant here. Thus, the adoption of the system of rice intensification (SRI), which aims to grow rice using less water through shortening the flooding periods can reduce the release of methane gas considerably. Additionally, government efforts should aim at packaging fertiliser subsidies in a way which promotes efficient use and private input market development.

Thus, the MI and MLI models achieve the objective of analysing productivity change trend and its components across some selected African countries and measured the environmentally adjusted productivity when bad output is accounted for. However, what the two models fail to achieve is decomposing productivity change into other finer components, especially the mix efficiency which is addressed in the next sub section results.

4.4 RESULTS OF FÄRE-PRIMONT PRODUCTIVITY INDEX

4.4.1 Annual TFP means and its components

Table 4.13 provides the FPI and its components. The average TFP level was 0.14, while the maximum TFP level obtained was 0.31, with the overall productive efficiency being 0.44. The technical, scale, mix, residual scale, residual mix and scale mix efficiencies were 0.89, 1.00, 0.95, 0.52 and 0.50, respectively. The output mix efficiency ranged between 0.92 and 0.97, with little variation evident over time. The residual scale, scale mix and residual mix efficiency was lower than the technical and scale efficiencies which implies that the countries surveyed failed to produce at the maximum productivity point despite being technically or scale efficient.

Table 4.14 provides the mean input use efficiencies for the examined period. It indicates that the technical, scale, mix, residual scale and scale mix efficiencies were 0.89, 1.00, 0.59, 0.85 and 0.50 respectively. The mean input mix efficiency ranged between 0.48 and 0.66, with the lowest mean input mix efficiency coinciding with those years when natural disasters occurred (see Table 4.3). The results underlie the fact that countries faced difficulties in adjusting their input mixes per the prevailing weather conditions. This failure to adjust input use is due to crop inputs being applied during planting hence providing little flexibility thereafter to adjust to the prevailing weather changes.

The results indicate high technical efficiencies on overall, suggesting that the twenty- seven African countries examined have maintained better use of inputs. However, differences among countries arise from the low mix efficiencies. The results also imply that while almost all countries use inputs efficiently to produce the near maximum potential output, they are not achieving economies of scope over time by having an optimum combination of input and output mixes. Thus, the prevailing gap between the observed TFP and the maximum frontier TFP emanates from lower levels of mix efficiency rather than technical efficiency.

Table 4.13 TFP and efficiency levels

Year	Maximum TFP level (TFP^*) 1	Technical efficiency level (OTE) 2	Scale efficiency level (OSE) 3	Mix efficiency level (OME) 4	Residual scale efficiency (ROSE) 5	Scale mix efficiency level (OSME) 6	Residual mix efficiency (RME) 7	TFP efficiency (TFPE) 8	TFP level 9
1980	0.23	0.89	1.00	0.95	0.55	0.52	0.52	0.46	0.10
1981	0.23	0.88	1.00	0.94	0.53	0.50	0.50	0.44	0.10
1982	0.24	0.87	1.00	0.95	0.51	0.49	0.49	0.42	0.10
1983	0.27	0.89	1.00	0.94	0.47	0.44	0.44	0.39	0.11
1984	0.25	0.90	1.00	0.95	0.49	0.46	0.46	0.41	0.10
1985	0.26	0.89	1.00	0.94	0.48	0.45	0.45	0.40	0.10
1986	0.26	0.90	1.00	0.94	0.49	0.46	0.46	0.41	0.11
1987	0.27	0.90	1.00	0.95	0.48	0.46	0.46	0.41	0.11
1988	0.28	0.89	1.00	0.95	0.47	0.45	0.45	0.40	0.11
1989	0.27	0.88	1.00	0.95	0.50	0.47	0.47	0.42	0.11
1990	0.27	0.90	1.00	0.94	0.52	0.49	0.49	0.44	0.12
1991	0.27	0.89	1.00	0.95	0.54	0.51	0.51	0.46	0.12
1992	0.28	0.89	1.00	0.95	0.52	0.49	0.49	0.44	0.12
1993	0.27	0.90	1.00	0.95	0.52	0.50	0.50	0.45	0.12
1994	0.28	0.91	1.00	0.95	0.54	0.51	0.51	0.46	0.13
1995	0.29	0.90	1.00	0.95	0.54	0.51	0.51	0.46	0.13
1996	0.28	0.90	1.00	0.95	0.56	0.53	0.53	0.47	0.13
1997	0.30	0.89	1.00	0.94	0.54	0.50	0.50	0.45	0.13
1998	0.30	0.90	1.00	0.93	0.55	0.51	0.51	0.46	0.14
1999	0.30	0.91	1.00	0.94	0.53	0.50	0.50	0.46	0.14
2000	0.33	0.90	1.00	0.96	0.51	0.49	0.49	0.44	0.15
2001	0.30	0.90	1.00	0.96	0.58	0.56	0.56	0.50	0.15
2002	0.41	0.90	1.00	0.96	0.44	0.42	0.42	0.38	0.16
2003	0.37	0.90	1.00	0.94	0.53	0.50	0.50	0.45	0.17
2004	0.39	0.89	1.00	0.92	0.52	0.48	0.48	0.42	0.17
2005	0.38	0.89	1.00	0.95	0.53	0.51	0.51	0.45	0.17

Year	Maximum TFP level (TFP*) 1	Technical efficiency level (OTE) 2	Scale efficiency level (OSE) 3	Mix efficiency level (OME) 4	Residual scale efficiency (ROSE) 5	Scale mix efficiency level (OSME) 6	Residual mix efficiency (RME) 7	TFP efficiency (TFPE) 8	TFP level 9
2006	0.35	0.88	1.00	0.96	0.59	0.56	0.56	0.49	0.17
2007	0.41	0.88	1.00	0.95	0.51	0.49	0.49	0.43	0.17
2008	0.39	0.86	1.00	0.97	0.55	0.54	0.54	0.46	0.18
2009	0.41	0.87	1.00	0.95	0.55	0.52	0.52	0.46	0.19
2010	0.36	0.88	1.00	0.97	0.60	0.58	0.58	0.51	0.18
2011	0.41	0.85	1.00	0.96	0.56	0.54	0.54	0.46	0.19
2012	0.41	0.86	1.00	0.97	0.54	0.52	0.52	0.45	0.18
Geomean	**0.31**	**0.89**	**1.00**	**0.95**	**0.52**	**0.50**	**0.50**	**0.44**	**0.14**

Source: Results estimates

Note: TFP = total factor productivity. This definition applies in preceding tables

Table 4.14 Summary of input usage: 1980-2012

Year	ITE	ISE	IME	RISE	ISME
1980	0.89	1.00	0.65	0.80	0.52
1981	0.88	1.00	0.66	0.77	0.50
1982	0.87	1.00	0.65	0.75	0.49
1983	0.89	1.00	0.66	0.67	0.44
1984	0.90	1.00	0.64	0.72	0.46
1985	0.89	1.00	0.65	0.70	0.45
1986	0.90	1.00	0.66	0.70	0.46
1987	0.90	1.00	0.62	0.74	0.46
1988	0.89	1.00	0.62	0.72	0.45
1989	0.88	1.00	0.58	0.81	0.47
1990	0.90	1.00	0.60	0.82	0.49
1991	0.89	1.00	0.58	0.88	0.51
1992	0.89	1.00	0.57	0.86	0.49
1993	0.90	1.00	0.61	0.82	0.50
1994	0.91	1.00	0.60	0.85	0.51
1995	0.90	1.00	0.55	0.93	0.51
1996	0.90	1.00	0.55	0.96	0.53
1997	0.89	1.00	0.58	0.87	0.50
1998	0.90	1.00	0.60	0.86	0.51
1999	0.91	1.00	0.57	0.87	0.50
2000	0.90	1.00	0.58	0.84	0.49
2001	0.90	1.00	0.58	0.95	0.56
2002	0.90	1.00	0.48	0.88	0.42
2003	0.90	1.00	0.51	0.97	0.50
2004	0.89	1.00	0.58	0.83	0.48
2005	0.89	1.00	0.53	0.97	0.51
2006	0.88	1.00	0.58	0.97	0.56
2007	0.88	1.00	0.53	0.91	0.49
2008	0.86	1.00	0.55	0.97	0.54
2009	0.87	1.00	0.57	0.92	0.52
2010	0.88	1.00	0.59	0.98	0.58
2011	0.85	1.00	0.56	0.97	0.54
2012	0.86	1.00	0.55	0.94	0.52
Geomean	**0.89**	**1.00**	**0.59**	**0.85**	**0.50**

Source: Results estimates

Note: ITE = input technical efficiency; ISE = input scale efficiency; IME = input mix efficiency; RISE = residual input scale efficiency and ISME = input scale mix efficiency. These definitions apply in preceding tables.

4.4.2 TFP growth and its components for the period 1980-2012

Table 4.15 provides the results for TFP growth rates and its components for the years 1980-2012. TFP change, technical change and overall productive efficiency (TFPE) growth was 1.82%, 2.19 % and 0.26% respectively. The technical, scale, mix, residual scale and scale mix efficiency growth rates were -0.07, 0%, 0.06%, 0.34% and 0.34%, respectively. The results reveal that technical progress and mix efficiency contributed substantively to positive TFP growth, with negligible contribution arising from technical and scale efficiency.

An examination of the input growth over the period as provided in Table 4.16 indicates an input technical efficiency growth of -0.07%, 0% growth in scale efficiency, -0.31% growth in mix efficiency, 0.76% growth in residual scale efficiency and 0.34% growth in the scale mix efficiency. The growth in input mix efficiency was considerably lower than the rest of the efficiencies, which implies a lower optimal combination of inputs. Non-optimal use of inputs is typical in many African countries and remains a major factor that hinders agricultural productivity growth. For example, Druilhe and Barreiro-Hurlé (2012) indicate that African farmers have high levels of inefficiencies due to high fertiliser prices, poor output price incentives, poor roads leading to high transportation costs, and lack of access to credit. Even for the few farmers who use inorganic fertilisers, they still fail to apply them at the recommended rates either due to the cost being too high or the fertiliser not being available at the right time (Shekania & Mwangi, 1996). Thus, improving farmer’s access to essential inputs for example improved seed varieties and inorganic fertiliser becomes a critical measure in improving Africa’s agriculture TFP growth.

Table 4.15 TFP change and its components

Year	Technical change (TC) 1	Technical efficiency change (TEC) 2	Scale efficiency change (SEC) 3	Mix efficiency change (OME) 4	Residual scale efficiency change (ROSE) 5	Scale mix efficiency change (OSME) 6	TFP Efficiency change (TFPE) 7	TFP change 8
1980	1.00	0.89	1.00	0.95	1.41	1.33	1.18	1.18
1981	1.03	0.88	1.00	0.94	1.37	1.30	1.14	1.18
1982	1.04	0.87	1.00	0.95	1.32	1.25	1.09	1.14
1983	1.20	0.89	1.00	0.94	1.21	1.14	1.01	1.21
1984	1.11	0.90	1.00	0.95	1.25	1.18	1.06	1.18
1985	1.15	0.89	1.00	0.94	1.23	1.16	1.03	1.19
1986	1.15	0.90	1.00	0.94	1.25	1.18	1.06	1.22
1987	1.19	0.90	1.00	0.95	1.23	1.17	1.05	1.24
1988	1.22	0.89	1.00	0.95	1.21	1.15	1.03	1.26
1989	1.19	0.88	1.00	0.95	1.28	1.22	1.07	1.28
1990	1.20	0.90	1.00	0.94	1.34	1.27	1.14	1.37
1991	1.19	0.89	1.00	0.95	1.38	1.32	1.17	1.39
1992	1.25	0.89	1.00	0.95	1.33	1.26	1.12	1.40
1993	1.22	0.90	1.00	0.95	1.35	1.28	1.15	1.40
1994	1.23	0.91	1.00	0.95	1.39	1.31	1.19	1.47
1995	1.27	0.90	1.00	0.95	1.39	1.32	1.18	1.50
1996	1.25	0.90	1.00	0.95	1.43	1.36	1.22	1.52
1997	1.33	0.89	1.00	0.94	1.38	1.29	1.16	1.53
1998	1.34	0.90	1.00	0.93	1.41	1.31	1.18	1.58
1999	1.35	0.91	1.00	0.94	1.37	1.29	1.18	1.58
2000	1.48	0.90	1.00	0.96	1.31	1.25	1.13	1.67
2001	1.34	0.90	1.00	0.96	1.49	1.43	1.29	1.73
2002	1.80	0.90	1.00	0.96	1.14	1.09	0.99	1.77
2003	1.64	0.90	1.00	0.94	1.36	1.28	1.15	1.89
2004	1.74	0.89	1.00	0.92	1.33	1.22	1.09	1.90
2005	1.68	0.89	1.00	0.95	1.37	1.31	1.16	1.95

Year	Technical change (TC) 1	Technical efficiency change (TEC) 2	Scale efficiency change (SEC) 3	Mix efficiency change (OME) 4	Residual scale efficiency change (ROSE) 5	Scale mix efficiency change (OSME) 6	TFP Efficiency change (TFPE) 7	TFP change 8
2006	1.55	0.88	1.00	0.96	1.51	1.45	1.27	1.97
2007	1.80	0.88	1.00	0.95	1.32	1.25	1.10	1.98
2008	1.71	0.86	1.00	0.97	1.42	1.38	1.19	2.03
2009	1.80	0.87	1.00	0.95	1.41	1.35	1.17	2.11
2010	1.59	0.88	1.00	0.97	1.54	1.49	1.31	2.09
2011	1.80	0.85	1.00	0.96	1.44	1.39	1.18	2.13
2012	1.80	0.86	1.00	0.97	1.39	1.34	1.16	2.08
Geomean	**1.36**	**0.89**	**1.00**	**0.95**	**1.35**	**1.28**	**1.14**	**1.55**
Growth (%)	**2.19**	**-0.07**	**0.00**	**0.06**	**0.34**	**0.34**	**0.26**	**1.82**

Source: Results estimates

Table 4.16 Summary of change in input usage

Year	dITE	dISE	dIME	dRISE	dISME
1980	0.89	1.00	1.14	1.17	1.33
1981	0.88	1.00	1.15	1.13	1.30
1982	0.87	1.00	1.14	1.09	1.25
1983	0.89	1.00	1.16	0.98	1.14
1984	0.90	1.00	1.13	1.05	1.18
1985	0.89	1.00	1.14	1.02	1.16
1986	0.90	1.00	1.16	1.02	1.18
1987	0.90	1.00	1.09	1.08	1.17
1988	0.89	1.00	1.09	1.06	1.15
1989	0.88	1.00	1.03	1.19	1.22
1990	0.90	1.00	1.06	1.19	1.27
1991	0.89	1.00	1.03	1.28	1.32
1992	0.89	1.00	1.00	1.26	1.26
1993	0.90	1.00	1.07	1.20	1.28
1994	0.91	1.00	1.06	1.24	1.31
1995	0.90	1.00	0.97	1.36	1.32
1996	0.90	1.00	0.97	1.40	1.36
1997	0.89	1.00	1.01	1.27	1.29
1998	0.90	1.00	1.05	1.25	1.31
1999	0.91	1.00	1.01	1.28	1.29
2000	0.90	1.00	1.02	1.23	1.25
2001	0.90	1.00	1.03	1.39	1.43
2002	0.90	1.00	0.85	1.29	1.09
2003	0.90	1.00	0.90	1.41	1.28
2004	0.89	1.00	1.01	1.21	1.22
2005	0.89	1.00	0.92	1.41	1.31
2006	0.88	1.00	1.02	1.42	1.45
2007	0.88	1.00	0.94	1.33	1.25
2008	0.86	1.00	0.97	1.42	1.38
2009	0.87	1.00	1.01	1.34	1.35
2010	0.88	1.00	1.05	1.43	1.49
2011	0.85	1.00	0.98	1.42	1.39
2012	0.86	1.00	0.97	1.38	1.34
Geomean	**0.89**	**1.00**	**1.03**	**1.24**	**1.28**
Growth (%)	**-0.07**	**0.00**	**-0.31**	**0.76**	**0.34**

Source: Färe-Primont Indexes estimates

Note: dITE = input technical efficiency; dISE = input scale efficiency; dIME = input mix efficiency; dRISE = residual input scale efficiency and dISME = input scale mix efficiency. These definitions apply in preceding tables.

4.4.3 TFP change and its components by country

Table 4.17 provides the TFP change for each country. The results indicate that Rwanda experienced the highest TFP change of 3.15%, with TFP efficiency change of 2.32%. Gambia had the lowest TFP change of 0.52%, with TFP efficiency change of 0.38%. Rwanda's high TFP change suggests that farmers are better in using inputs optimally and are operating at optimum scale especially after reforms following the 1994 civil conflict. Gambia's low productivity change was because of low technical efficiency change.

Technical efficiency change of the countries survey varied: fourteen countries attained maximum efficiency of 1.00, while Zambia had the lowest score of 0.35. Technical change remained constant across countries, with a change of 1.36%. A constant technical change is consistent with the results of Rahman and Salim (2013); Tozer and Villano (2013). Scale efficiency was 1.00 for all the countries due to constant returns to scale being used. For OME twelve countries were efficient with Ghana being the least efficient with a score of 0.75. All countries experienced positive change in residual scale efficiency (ROSE), residual mix efficiency (RME) and scale mix efficiency (OSME) with Rwanda having a score of 2.32% in each of the efficiencies while Gabon had the lowest change of 0.54% in ROSE, RME and OSME.

The results indicate that countries that experienced high TFP change also had high technical and mix-efficiency changes. Decisions taken by some of the countries are seen to account for high TFP change. For example, Tunisia's agriculture development efforts since the reform period of the 1980's encouraged public and private investments in agriculture by ensuring a reformed agriculture marketing system, encouraging technology adoption and putting in place an effective agriculture extension service all of which sustained and enhanced agricultural productivity (Aoun, 2004). Kenya's improved TFP change is due to the advantage of having a well-established agro-food processing industry and other supporting manufacturing sectors. Kenya is consequently one of the major growers and exporters of horticultural crops and products in Africa (Diao et al., 2010). Nigeria and South Africa are also large producers. Although Egypt and Algeria have less favourable climatic conditions characterised by poor or unreliable rainfall, their high TFP change suggest that these countries respond to the unfavourable weather changes better than the coastal countries such as Zambia, Mozambique and Malawi, which have favourable climatic conditions (Diao, et al., 2007). Countries such as Malawi and Zambia that are large maize producers, had lower TFP change due to low mix efficiency change. During the 1980s and early 1990s, Malawi and Zambia channelled their resources such as agriculture credit, input and extension services to smallholder farmers at subsidised rates thus neglecting other important crops (Zeller, et al., 1998). Mozambique's low agricultural TFP is a product of many years of civil which led to the destruction of infrastructure and the reduction of livestock and lack of appropriate technologies for example the unavailability of inorganic fertilisers and seed varieties (Guanziroli & Frischtak, 2011). Gambia's experience of low TFP change, OTE and OME efficiency is evidence of the country being distant from the production frontier and therefore not achieving an optimal combination of outputs. Gambia which is among the African countries with high levels of poverty levels, suffers from low productivity in the agriculture sector (IMF, 2000).

An examination of mean input change by country (Table 4.18) indicates that sixteen countries had gained optimum input use. Zambia has the lowest score of 0.35, indicating the country's inability to use inputs optimally. Although Zambia widely adopted the fertiliser subsidy programme, the score indicates that the country did not achieve input efficiency. Angola, Gabon, Gambia, Libya, Niger, Mali, Mozambique and Sudan (Former) had a low input mix and input scale mix efficiency, which indicates a gap in capacity needed to achieve the right combination of inputs and scale of operations. Countries that were not technically efficient also had low mix efficiency, which implies they were unable to efficiently combine the inputs or outputs.

Table 4.17 TFP change and its components (by country)

Country	TFP efficiency change (TFPE)	Technical change (TC)	Technical efficiency change (OTE)	Scale efficiency change (OSE)	Mix efficiency change (OME)	Residual scale efficiency change (ROSE)	Scale mix efficiency change (OSME)	TFP change	Rank
Rwanda	2.32	1.36	1.00	1.00	1.00	2.32	2.32	3.15	1
Uganda	2.25	1.36	1.00	1.00	1.00	2.25	2.25	3.06	2
Côte d’Ivoire	2.20	1.36	1.00	1.00	1.00	2.20	2.20	2.98	3
Nigeria	2.08	1.36	1.00	1.00	1.00	2.08	2.08	2.83	4
Ghana	1.91	1.36	0.91	1.00	0.94	2.24	2.11	2.60	5
Algeria	1.83	1.36	1.00	1.00	1.00	1.83	1.83	2.49	6
Burundi	1.78	1.36	1.00	1.00	1.00	1.78	1.78	2.42	7
Tunisia	1.73	1.36	1.00	1.00	1.00	1.73	1.73	2.36	8
Egypt	1.70	1.36	1.00	1.00	1.00	1.70	1.70	2.30	9
South Africa	1.39	1.36	1.00	1.00	1.00	1.39	1.39	1.89	10
Cameroon	1.38	1.36	0.97	1.00	0.99	1.43	1.42	1.87	11
Kenya	1.35	1.36	1.00	1.00	0.92	1.48	1.36	1.84	12
Tanzania	1.14	1.36	0.86	1.00	0.92	1.44	1.33	1.56	13
Madagascar	1.00	1.36	1.00	1.00	0.99	1.01	1.00	1.35	14
Malawi	0.99	1.36	0.82	1.00	0.92	1.31	1.21	1.34	15
Mali	0.91	1.36	1.00	1.00	1.00	0.91	0.91	1.23	16
Burkina Faso	0.91	1.36	0.86	1.00	0.79	1.33	1.05	1.23	17
Togo	0.90	1.36	0.85	1.00	0.94	1.13	1.06	1.23	18
Sudan (former)	0.89	1.36	1.00	1.00	1.00	0.89	0.89	1.21	19
Libya	0.86	1.36	1.00	1.00	0.99	0.88	0.87	1.17	20
Niger	0.85	1.36	1.00	1.00	1.00	0.85	0.85	1.15	21
Zimbabwe	0.84	1.36	0.75	1.00	0.84	1.34	1.12	1.14	22
Mozambique	0.76	1.36	0.83	1.00	0.92	0.99	0.91	1.03	23
Angola	0.67	1.36	0.84	1.00	0.78	1.03	0.80	0.92	24
Zambia	0.59	1.36	0.35	1.00	0.85	1.96	1.67	0.80	25

Country	TFP efficiency change (TFPE)	Technical change (TC)	Technical efficiency change (OTE)	Scale efficiency change (OSE)	Mix efficiency change (OME)	Residual scale efficiency change (ROSE)	Scale mix efficiency change (OSME)	TFP change	Rank
Gabon	0.54	1.36	1.00	1.00	1.00	0.54	0.54	0.73	26
Gambia	0.38	1.36	0.50	1.00	0.92	0.84	0.77	0.52	27

Source: Results estimates

Table 4.18 Input use change across selected countries

Country	dITE	dISE	dIME	dRISE	dISME	dRME
Algeria	1.00	1.00	1.64	1.12	1.83	1.83
Angola	0.84	1.00	0.70	1.15	0.80	0.80
Burkina Faso	0.86	1.00	0.88	1.20	1.05	1.05
Burundi	1.00	1.00	1.38	1.29	1.78	1.78
Cameroun	0.97	1.00	1.07	1.33	1.42	1.42
Côte d'Ivoire	1.00	1.00	1.58	1.39	2.20	2.20
Egypt	1.00	1.00	1.26	1.34	1.70	1.70
Gabon	1.00	1.00	0.44	1.22	0.54	0.54
Gambia	0.50	1.00	0.58	1.32	0.77	0.77
Ghana	0.91	1.00	1.56	1.35	2.11	2.11
Kenya	1.00	1.00	1.26	1.08	1.36	1.36
Libya	1.00	1.00	0.75	1.15	0.87	0.87
Madagascar	1.00	1.00	0.82	1.21	1.00	1.00
Malawi	0.82	1.00	0.87	1.40	1.21	1.21
Mali	1.00	1.00	0.83	1.10	0.91	0.91
Mozambique	0.83	1.00	0.66	1.38	0.91	0.91
Niger	1.00	1.00	0.79	1.07	0.85	0.85
Nigeria	1.00	1.00	1.51	1.38	2.08	2.08
Rwanda	1.00	1.00	1.62	1.43	2.32	2.32
South Africa	1.00	1.00	1.29	1.07	1.39	1.39
Sudan (Former)	1.00	1.00	0.88	1.01	0.89	0.89
Togo	0.85	1.00	0.75	1.42	1.06	1.06
Tunisia	1.00	1.00	1.35	1.28	1.73	1.73
Uganda	1.00	1.00	1.60	1.41	2.25	2.25
Tanzania	0.86	1.00	1.05	1.27	1.33	1.33
Zambia	0.35	1.00	1.46	1.14	1.67	1.67
Zimbabwe	0.75	1.00	0.97	1.16	1.12	1.12

Source: Results estimates

4.4.4 TFP growth rates (%) across countries

Table 4.19 provides the mean TFP growth rates and its components across the countries. The results reveal that TFP growth emanated from growth in TFP efficiency change rather than technical change, with most countries experiencing growth in TFP over the period. Malawi experienced the highest TFP growth of 5.79%. Growth in technical change remained constant for all countries, at 2.19%, which is consistent with studies using the Färe-Primont TFP index.

TFP efficiency change growth varied across countries with nine countries (Zimbabwe, Burkina Faso, Madagascar, Niger, Sudan (Former), Gambia, Kenya, Uganda and Burundi) experiencing a decline. Regarding technical efficiency change, Zambia (-0.69%), Angola (-0.36%), Zimbabwe (-0.85%) and Gambia (-1.4%) had a decline while Malawi (0.73%), Libya (0.45%), Cameroun (0.04%), Mozambique (2.15%), Ghana (1.14%), Togo (1.12%), Burkina Faso (1.16%) and Kenya (0.01%) had growth.

Twelve countries did not experience a change in mix efficiency while Malawi (-0.43%), Ghana (-0.22%) and Zimbabwe (-0.27%) experienced a decline. The rest of the countries experienced growth i.e. Libya (0.03%), Zambia (1.35%), Cameroun (0.01%), Mozambique (0.56%), Angola (1.6%), Togo (0.28%), Tanzania (0.74%), Burkina Faso (0.58%), Madagascar (0.03%), Sudan (Former)(0.05%), Gambia (0.03%) and Kenya (0.09%).

Residual scale efficiency and scale mix efficiency growth was positive in almost all the countries except in Togo, Burkina Faso, Madagascar, Sudan (Former), Kenya, Uganda and Burundi which experienced negative growth.

The negative change in mix efficiency indicates that some countries did not achieve the right combination of inputs or outputs, while the negative scale mix efficiency provide an indication that some countries failed to achieve the optimal scale of operations and right input or output mix. Thus, policies that would guarantee farmers attain optimal technical, mix and scale efficiency would help address the productivity lag among the African countries.

Table 4.19 TFP and its components growth rates (by country)

Country	TFP efficiency change (TFPE)	Technical change (TC)	Technical efficiency change (OTE)	Scale efficiency change (OSE)	Mix efficiency change (OME)	Residual scale efficiency change (ROSE)	Scale mix efficiency change (OSME)	TFP change	Rank
Malawi	5.04	2.19	0.73	0.00	-0.43	4.97	3.90	5.79	1
Algeria	4.02	2.19	0.00	0.00	0.00	4.02	4.02	5.45	2
Libya	3.24	2.19	0.45	0.00	0.03	2.94	2.92	4.57	3
Zambia	1.92	2.19	-0.69	0.00	1.35	1.42	3.03	3.29	4
Cameroon	1.60	2.19	0.04	0.00	0.01	1.56	1.56	3.15	5
Tunisia	0.81	2.19	0.00	0.00	0.00	0.81	0.81	3.10	6
Mozambique	1.35	2.19	2.15	0.00	0.56	1.63	2.10	2.96	7
Angola	1.15	2.19	-0.36	0.00	1.60	2.13	2.70	2.77	8
Ghana	1.14	2.19	1.14	0.00	-0.22	0.21	0.00	2.75	9
Egypt	1.02	2.19	0.00	0.00	0.00	1.02	1.02	2.73	10
South Africa	1.24	2.19	0.00	0.00	0.00	1.24	1.24	2.68	11
Togo	0.83	2.19	1.12	0.00	0.28	-0.27	-0.10	2.51	12
Côte d’Ivoire	0.78	2.19	0.00	0.00	0.00	0.78	0.78	2.38	13
Rwanda	0.84	2.19	0.00	0.00	0.00	0.84	0.84	2.35	14
Nigeria	0.13	2.19	0.00	0.00	0.00	0.13	0.13	2.01	15
Tanzania	0.41	2.19	0.07	0.00	0.74	1.96	1.30	1.89	16
Zimbabwe	-0.07	2.19	-0.85	0.00	-0.27	1.73	1.40	1.74	17
Gabon	0.19	2.19	0.00	0.00	0.00	0.19	0.19	1.66	18
Mali	0.02	2.19	0.00	0.00	0.00	0.02	0.02	1.60	19
Burkina Faso	-0.03	2.19	1.16	0.00	0.58	-1.49	-0.99	1.55	20
Madagascar	-0.08	2.19	0.00	0.00	0.03	-0.11	-0.08	1.47	21
Niger	-0.02	2.19	0.00	0.00	0.00	-0.02	-0.02	1.44	22
Sudan (former)	-0.25	2.19	0.00	0.00	0.05	-0.28	-0.25	1.38	23
Gambia	-0.57	2.19	-1.40	0.00	0.03	1.75	1.35	1.31	24
Kenya	-0.19	2.19	0.01	0.00	0.09	-0.18	-0.23	1.30	25

Country	TFP efficiency change (TFPE)	Technical change (TC)	Technical efficiency change (OTE)	Scale efficiency change (OSE)	Mix efficiency change (OME)	Residual scale efficiency change (ROSE)	Scale mix efficiency change (OSME)	TFP change	Rank
Uganda	-1.14	2.19	0.00	0.00	0.00	-1.14	-1.14	0.47	26
Burundi	-1.14	2.19	0.00	0.00	0.00	-1.14	-1.14	0.43	27

Source: Results estimates

Table 4.20 Mean input growth rate (%) and its components (by country)

Country	dITE	dISE	dIME	dRISE	dISME	dRME
Algeria	0.00	0.00	2.08	1.82	4.02	4.02
Angola	-0.36	0.00	1.30	1.46	2.70	2.70
Burkina Faso	1.16	0.00	-1.76	1.33	-0.99	-0.99
Burundi	0.00	0.00	-1.30	0.14	-1.14	-1.14
Cameroun	0.04	0.00	1.34	0.25	1.56	1.56
Côte d'Ivoire	0.00	0.00	0.68	-0.03	0.78	0.78
Egypt	0.00	0.00	1.38	0.20	1.02	1.02
Gabon	0.00	0.00	-0.74	1.10	0.19	0.19
Gambia	-1.40	0.00	0.86	0.82	1.35	1.35
Ghana	1.14	0.00	0.13	0.07	0.00	0.00
Kenya	0.01	0.00	-1.24	2.02	-0.23	-0.23
Libya	0.45	0.00	1.81	1.49	2.92	2.92
Madagascar	0.00	0.00	-0.94	1.12	-0.08	-0.08
Malawi	0.73	0.00	3.38	0.14	3.90	3.90
Mali	0.00	0.00	-1.45	2.03	0.02	0.02
Mozambique	2.15	0.00	1.91	0.24	2.10	2.10
Niger	0.00	0.00	-1.19	2.17	-0.02	-0.02
Nigeria	0.00	0.00	-0.08	0.31	0.13	0.13
Rwanda	0.00	0.00	0.50	0.10	0.84	0.84
South Africa	0.00	0.00	0.46	1.58	1.24	1.24
Sudan (Former)	0.00	0.00	-0.96	1.67	-0.25	-0.25
Togo	1.12	0.00	-0.17	0.09	-0.10	-0.10
Tunisia	0.00	0.00	0.82	0.33	0.81	0.81
Uganda	0.00	0.00	-1.42	0.21	-1.14	-1.14
Tanzania	0.07	0.00	0.93	0.65	1.30	1.30
Zambia	-0.69	0.00	1.38	1.89	3.03	3.03
Zimbabwe	-0.85	0.00	1.18	1.39	1.40	1.40

Source: Results estimates

4.4.5 TFP growth rates across regions

Table 4.21 provides the performance of the countries when grouped into the regions of: Eastern Africa (Burundi, Kenya, Madagascar, Malawi, Mozambique, Rwanda, Uganda and Tanzania), Western Africa (Burkina Faso, Côte d'Ivoire, Gambia, Ghana, Mali, Niger, Nigeria and Togo), Southern Africa (South Africa, Zambia and Zimbabwe), Central Africa (Angola, Cameroun and Gabon) and Northern Africa (Algeria, Egypt, Libya, Tunisia and Sudan (Former)) based on their geographical location.

The results reveal that the overall agricultural productivity growth is led by the Northern Africa region with 2.65% growth per annum followed by the Central African region with TFP growth of 2.4% per annum. Northern Africa's impressive productivity performance is due to various factors such as better infrastructure, high macroeconomic stability, higher education attainment, an efficient market for goods and existence of innovations, among other factors (Africa, 2011). The Eastern Africa region lags with TFP growth of 1.45% per annum. The Northern and Southern Africa regions had a high overall productive efficiency with growth in technical efficiency and mix efficiencies, while the Central region although it had positive overall productive efficiency growth and mix efficiency, it suffered declining technical efficiency. Only the Western Africa region had growth in technical efficiency and output mix efficiency with declining overall productive efficiency and the other mix efficiencies. The Eastern Africa region had a low contribution of overall productive efficiency, technical efficiency, output mix scale mix efficiency, with a declining output mix and residual output scale efficiency.

Table 4.21 TFP growth rates across regions

Region	dTFP	dTech	dTFPE	dOTE	dOSE	dOME	dROSE	dOSME	dRME
Northern	2.65	2.19	0.98	0.08	0.00	0.00	0.89	0.91	0.91
Central	2.40	2.19	0.85	-0.27	0.00	0.40	1.00	1.27	1.27
Southern	2.32	2.19	0.79	-0.73	0.00	0.27	1.27	1.60	1.60
Western	1.52	2.19	-0.14	0.12	0.00	0.01	-0.26	-0.25	-0.25
Eastern	1.45	2.19	0.03	0.05	0.00	-0.01	-0.02	0.01	0.01

Source: Results estimates

4.4.6 Determinants of TFP

The BMA technique was used to identify the TFP determinants in agriculture of the twenty-seven African countries by regressing the Färe-Primont estimates against the following attributes: agriculture R&D spending; area irrigated; political stability; average years of schooling (of adults); per capital land and the ratio of HIV prevalence among adults.

Table 4.22 provides the TFP determinants results. The post mean indicates results of the coefficients averaged over all models. Agriculture R&D spending, HIV prevalence and mean years of schooling had posterior inclusion probabilities (PIP) of 1.00. Per capita land and political stability had a PIP of 0.999 each. The coefficients posterior probability (Cond. Pos. Sign) indicates the sign certainty on the expected value conditional on including each variable which was negative for the variables HIV prevalence, political instability, per capita land and area irrigated while agriculture R&D spending and mean years of schooling had a positive sign certainty.

The results thus imply that with 100% confidence, all the posterior model mass rests on models that include agriculture R&D spending, HIV prevalence and mean years of schooling. Per capita land and political instability's PIP of 0.99 indicates that with 99.9% confidence, all the posterior mass rests on models that include per capita land and political instability. The area irrigated had a PIP of 0.05 (5%) implying that the variable did not significantly affect productivity and was therefore not important. This suggests that results may generally include models where the area irrigated coefficient appears zero.

Agricultural R&D spending was positively associated with TFP, implying that countries spending more on agriculture research achieve higher TFP growth rates than countries which did not. The finding confirms the results of Fuglie and Rada (2013) and Alene (2010), that research and development expenditure positively affect agricultural TFP growth.

HIV prevalence was negatively associated with TFP, corroborating the findings of Fox et al. (2004) that HIV/AIDS negatively impacts labour productivity among agriculture estate workers in Kericho, Kenya by affecting labour supply and livelihoods (income).

Per capita land had a negative relationship with TFP, indicating that increasing land reduced agricultural TFP growth. The results coincide with the existing findings on the impact of farm size on productivity. That is, farmer's management practises, labour or other constraints may often limit large scale farmers from being as productive as small scale farmers (Pender et al., 2006). African agriculture heavily depends on expanding agricultural land and hence requires increased alternative and sustainable sources of agriculture TFP growth.

Average years of schooling as a proxy for education had a positive relationship with TFP. Indeed, in some existing studies, a positive association has been found between human capital and TFP growth (Benhabib & Spiegel, 1994, 2005). Hence, improving education in Africa appears to be an important factor in helping to improve TFP growth in the agriculture sector.

Political stability as a proxy of governance had a negative relationship with TFP, which indicates that political threats lead to a decline in TFP growth. The findings by Kimuyu (2005) indicate that when socio-economic and political uncertainties exist then the discount factors which discourage long-term decision making come into play.

The area irrigated had a negative relationship with TFP, although the variable was not significant due to its low PIP.

Table 4.22 Determinants of TFP

Variable	PIP	Post Mean	Post SD	Cond Pos Sign	Idx
Intercept	1.000	1.823	NA	NA	0
Agricultural spending	1.000	0.294	0.045	1.000	1
HIV prevalence	1.000	-0.414	0.048	0.000	3
Education	1.000	0.377	0.049	1.000	4
Irrigation area	0.054	-0.000	0.011	0.000	2
Per capita land	0.999	-0.246	0.046	0.000	6
Political stability	0.999	-0.207	0.044	0.000	5

Source: Results estimates
Note: PIP = posterior inclusion probabilities; Post SD = posterior standard deviation; Cond Pos = posterior probability of a positive coefficient; Idx = index of the variables as they appeared in the original data

4.4.7 Summary of the findings and implications

TFP change was decomposed into its finer components of technical, scale and mix efficiencies. The average TFP change and its components for all the twenty-seven countries for the period 1980 to 2012 was low. Although the technical efficiency was high, the residual scale and mix efficiencies were low, implying that most of the countries failed to operate at maximum productivity even though they operated closer to the frontier in their use of inputs.

The average input mix efficiency was considerably lower than the input technical or scale efficiency, indicating that farmers experience difficulties in adjusting the input mixes to match with the prevailing weather conditions. The results revealed a high level of technical efficiency for the countries surveyed, implying an efficient use of inputs. However, the difference in efficiency was in terms of the residual scale efficiency, scale mix efficiency and in getting the right mix of inputs which suggest that the gap between the observed TFP and the frontier TFP is due to low mix efficiency levels. Thus, although African countries have maintained high technical and scale efficiency, they have failed to attain optimal scale and scope of operations and input-output mixes (scale mix efficiency) in their agriculture sectors, thereby widening the productivity gap. Importantly, these results help to correct the existing literature's notion that technical change or efficiency maybe the only cause of declining TFP growth in African countries.

The determinants of TFP included agriculture R&D spending and mean years of schooling, which had a positive relationship with TFP. Per capita land, political instability and HIV prevalence negatively impacted TFP. Thus, policies that would improve agriculture R&D research such as providing improved seed and livestock breeds and raising education levels becomes key to agriculture TFP growth. Improving health care would help improve the well-being of HIV infected people hence improving labour productivity. As well, improving governance through political and economic stability will also help improve TFP.

PART II – RICE FARMING AND PROCESSING IN KENYA

Chapter 5: Rice farming and processing in Kenya

5.1 INTRODUCTION

Rice farming remains an important undertaking in Asia and Africa due to its important role in maintaining essential food supply (Bishwajit et al., 2013; Enwerem & Ohajianya, 2013; Heriqbaldi et.al, 2014; Kadiri et al., 2014; Khai & Yabe, 2011; Mushtaq et.al, 2009). Rice remains one of the key global food crops, ranking second to maize and providing more than one-fifth of the calories consumed worldwide (Dawe et al., 2010).

Rice demand in Africa has risen steadily, with an increase of more than 50% reported in some countries since the year 2005 and with an even higher growth in demand projected in several countries (Calpe, 2006). Globally, 112 million tonnes of additional rice will be needed by the year 2040, with 40% of this projection emanating from Africa. For example, in Central and Eastern Africa regions, a 300% growth in demand for rice is expected between 2010 and 2050 due to rapid population growth and increased purchasing power (Zuberi & Thomas, 2012). Africa is likely to emerge as a growing rice importer, if rice output does not keep pace with the rising demand (Mohanty, 2013). Most governments remain major players in rice farming through providing irrigation facilities, input supplies or credit, thus making the policy settings to have a significant influence on an individual farmer’s incentive to increase output.

Rice has attained the status of a staple food crop in Kenya, and is now ranked third after maize and wheat. Kenya’s rice demand is growing much more rapidly than output, with the annual estimated rice consumption of 400,000 tonnes exceeding the annual output estimated at 110,000 tonnes. Kenya’s annual rice consumption has been increasing at an annual rate of 12% on average in recent years in contrast to other staple food crops especially wheat and maize whose current demand is lower at 4% and 1% respectively (Short et al., 2012). Moreover, Kenya’s future demand for rice is anticipated to continue to increase due to rising income and urbanisation. The growing gap between demand for rice and supply is being met by imports and therefore imposing a considerably foreign exchange burden (RoK, 2010b). Kenya’s rice import dependency ratio is currently more than 80%, with locally produced rice meeting only 20% of the demand (see Appendix I). This implies that the Kenyan rice farmers and millers need to greatly improve their efficiency to increase rice supply. Furthermore, a gain in efficiency is likely to benefit farmers through raising their farm incomes.

The Kenya National Rice Development Strategy (NRDS) aims at increasing rice output to 178,580 MT/year by 2018 to stabilise the rice market. The NRDS strategies include using quality inputs, providing extension services, promoting machine use and improving post-harvest practices. However, the NRDS’s major shortcoming is that it has directed its emphasis and resources towards producing rice by encouraging the use of improved seed varieties and fertiliser use while ignoring the milling process. Rice milling efficiency remains important since paddy and rice losses during the post-harvest process amount to about 10% of field output (Hodges et.al., 2011). Generally, in the last thirty years, only 5 percent of the research effort has been directed towards reducing post-harvest losses, with 95 percent of the effort focusing on increasing farm productivity (Kader, 2004; Kitinoja & AlHassan, 2010).

Improving rice milling efficiency will help reduce losses thereby not only bringing an economic gain to the millers, but also contributing to Kenya's food security. Furthermore, by promoting rice farming and processing, the over-reliance on maize as a staple food will be reduced leading to improvement in rural and urban households’ incomes and food security. As the Kenyan market heavily relies on rice imports, improving technical, cost and allocative efficiency will help the sector enhance its competitive advantage.

After reviewing the literature on rice farming in Kenya, this study has identified the following gaps:

1) No previous study examines the technical, cost and allocative efficiency of Kenya’s rice farming regions as well as the regional technological gaps.
2) No study has captured Kenya’s rice processing efficiency and particularly the environmental efficiency of rice processing within the agri-food system.

3) No study has evaluated the two stages of rice processing, i.e., drying and milling.

This part of the thesis uses field survey data of 800 rice farmers and 150 rice millers in Kenya to evaluate efficiency across the rice agroecological zones using data envelopment analysis (DEA) and fractional regression model techniques. It also examines the two stages of rice processing (milling and drying) using network DEA. First, the thesis investigates the technical, cost and allocative efficiency of Kenya's rice farming sector and its determinants. Second, the technical, cost, allocative and environmental efficiency of rice processing is examined. Lastly, the thesis will capture the two stages of rice processing, i.e., drying and milling. Through this analysis and interpretation of rice farming and processing efficiency measures, policy-makers will be provided with insights that will assist them in mobilising adequate resources to improve rice productivity in the country. The research is also designed to help policy-makers to adjust the rice sector research agenda appropriately.

Section 5.2 examines rice farming literature, 5.3 reviews the rice processing literature and 5.4 provides a summary and implications of the study.

5.2 LITERATURE ON RICE FARMING

There exists a significant number of studies in the literature focusing on technical and allocative efficiency of various crops in different regions or countries (Gebregziabher et al., 2012; Iraizoz et al., 2003; Latruffe, et al., 2004; Sekhon et al., 2010; Wadud, 2003). Studies on rice farming efficiency that exist in the literature include the analysis of rice production in the Philippines (Pate & Cruz, 2007; Yao & Shively, 2007 and Villano & Fleming, 2006). Khai and Yabe (2011) examined rice farming in Vietnam while Tian & Wan (2000) have examined the technical efficiency of grain (rice, wheat and corn) production and its determinants in China. Coelli et.al. (2002) examined the efficiency (technical, allocative, cost and scale) of 406 rice farms in 21 villages of Bangladesh for the year 1997 and found a difference in mean efficiency results between the dry (Boro) and wet (Aman) seasons. Chang & Wen (2011) analysed the technical efficiency and production risk for two categories of rice farmers in Taiwan i.e. those with off-farm work and those without off-farm work and found differences in resource use among the two categories of rice farmers. The authors found that the farmers with off-farm work faced a higher production risk than those without off-farm income and that off farm income reduced inefficiency among the lower percentiles farmers.

Although several studies on agriculture technical efficiency at the micro-level exist for Kenya (see Seyoum et al., 1998; Mochebelele & Winter, 2002), the bulk of these studies have been limited to a sample of farms mostly in the high potential zones and of dairy farmers. A few studies on rice farming in Kenya exist, mainly focusing on specific regions. For example, Omondi and Shikuku (2013) used the Cobb Douglas production function to evaluate Ahero irrigation scheme's rice farming efficiency for 220 rice farmers and found the average technical efficiency to be 0.82. The authors established that the gender of the rice farmer, rice farming experience, the farmer's income levels and market distance significantly affected efficiency. Mati et al. (2011) and Nyamai et al. (2012) evaluated the impact of adopting the system of rice intensification (SRI) among the rice farmers at the Mwea Irrigation Scheme. They found that the SRI had more benefits than the conventional method of rice growing, since it saved on water, seed, fertiliser and pesticides use, hence cutting rice farming costs. Gitau et al. (2011) evaluated Kenya's trade and agriculture competitiveness in wheat and rice, and found inefficiencies along the rice chain which included: high labour costs, high migration rate and high fertiliser/seed costs. Kuria et al. (2003) examined Mwea's rice farming efficiency by comparing one-season and two-season rice producers and found that farmers growing a single crop of rice annually to be more efficient than those growing a double crop.

The above review indicates that the studies fail to provide an in-depth analysis of Kenya's rice farming system and of the factors that determine the efficiency levels. Rice in Kenya is cultivated under diverse agroecological conditions, which means farmers face different production technologies and opportunities, and therefore may make decisions based on the input-output level choices they make (O'Donnell et al., 2008). Hence, the assumption that farmers use the same technology can lead to biased results and that unobserved differences in production techniques may be inappropriately labelled as technical inefficiency (Villano et al., 2010; Jiang & Sharp, 2015). Currently, no study exists on the technical, cost and allocative efficiency across the rice agro-ecological zones of Kenya, a gap that this study attempts to fill. To do so, the study examines rice farming efficiencies (technical, cost and allocative) and the technology gaps across four rice agro-ecological zones of Kenya, i.e., Mwea, Ahero, West Kano and Bunyala irrigation schemes and investigates the factors that determine the efficiency levels.

5.3 LITERATURE ON RICE PROCESSING

There are a handful of studies on rice processing in the literature. Among them are Basorun (2008) who examined the factors affecting rice processing in Igbemo, Nigeria. The study found a strong relationship between efficiency scores and gender, income, training, type of processing activities, the number of workers, mode of processing, access to raw material, processing expenditure, institutional assistance and storage facilities availability. Ibitoye et al. (2014) assessed rice processing in the Bassa area of Kogi state, Nigeria, and established that rice processing was profitable, and income, educational status, household size, distance and gender influenced the net return. Fu et al. (2011) examined China's food processing sector and found low technical efficiency scores for both flour and rice processing, with an efficiency level of only about 50%. From the literature, it is clear then, most existing rice farming or processing efficiency studies solely focus on technical efficiency, while ignoring other critical components such as allocative and cost-efficiency.

Similarly, although agricultural processes yield a range of good outputs (food, fibre, bioenergy, medicines, etc.), alongside them are bad outputs being generated. Studies that incorporate bad outputs are generally limited to manufacturing with little application to agriculture food processing (see Chiu, et al., 2012; Nakano & Managi, 2010; Skevas et al., 2012; Zhang, 2008). Further, the bulk of the studies on food processing focus on developed country contexts and mainly on the dairy and meat industry, few deal with crop processing context. Moreover, limited work has been carried out on estimating the environmental efficiency of agricultural crop processing systems which should play a significant role in reducing emission. Although the rice milling industry remains among the highest energy consuming sectors within the agri-food processing systems, the effect of the energy used remains unevaluated (Goyal et al., 2014). Rice milling industry being a high-energy consumer, thus necessitates the need to investigate the efficiency while incorporating CO_2 emissions.

Furthermore, rice processing is assumed to consist of only one stage i.e. the milling process while the drying process is rarely examined yet it affects the amount and quality of paddy processed. In the case of Kenya, no study has addressed the rice processing efficiency and in addition no study has ever evaluated rice processing efficiency while incorporating bad outputs. This study consequently has two primary objectives. First, it will assess the technical, cost, allocative and environmental efficiency of Kenya's rice processing sector. Second, the study will examine the two stages of processing i.e. drying and milling

The study's outcomes are designed to reveal any critical policy gaps which need strengthening to improve rice farming and processing of Kenya.

5.4 SUMMARY AND IMPLICATIONS

The literature review examined several studies on rice farming and rice processing in Kenya and other countries, revealing that they were specific country and region focused thus generalising rice productivity in a country. These studies rarely tackled possibility of technology gaps existing across the regions. Again, much emphasis is on measuring technical efficiency while ignoring other equally important efficiencies such as cost and allocative efficiency.

Rice studies were few in the literature although processing affects the amount and quality of rice processed. Rice processing is also a high-energy consumer among the agri-food processing systems, a component not yet examined in the studies reviewed. Moreover, measuring the efficiency of rice processing employs the standard DEA method which does not accurately represent the post-harvest production model. All the studies on rice processing consider it as a one stage process hence none evaluate the two stages of rice processing i.e. rice milling and rice drying.

The results of this analysis will provide useful information to policy-makers on target areas that will help boost rice productivity.

Chapter 6: Research methodology and primary data source

6.1 INTRODUCTION

The research methodology and data sources is provided in this chapter. Section 6.2 discusses the DEA method of estimating efficiency, while 6.3 and 6.4 discuss the network DEA method and the fractional regression model respectively. Section 6.5 discusses the study sites while 6.6 provides the ethical considerations of the study. Section 6.7 sets out the sampling and data collecting methods while 6.8 outlines the funding source. The challenges faced during the field survey are provided in Section 6.9.

6.2 COMPUTING EFFICIENCY USING DEA METHOD

6.2.1 Input/output oriented efficiency

In DEA, the input or output-oriented models may be used. The input-oriented approach to technical efficiency estimates to what extent a DMU could reduce the resources employed and still produce the same output level. This represents the DMU's resource intensity relative to best practice. The output-oriented DEA determines to what extent a DMU could increase its output level while employing the same level of resources.

When a DMU is on the best practice frontier, then it is deemed to be efficient, and inefficient if vice versa. The linear programme solved for the ith firm/farm when using the output-oriented approach, can be represented as follows;

$Max\Phi_1$

Subject to:

$$\Phi_1 y_{k,m} \leq \sum_{k=1}^{K} Z_k\, y_{k,m} \qquad \forall m \qquad (6.1)$$

$$\sum_{k=1}^{K} Z_k\, x_{k,n} \leq x_{k,n} \qquad n \in \alpha \qquad (6.2)$$

$$\sum_{k=1}^{K} Z_k\, x_{k,m} = \lambda_{k,n} x_{k,n} \qquad n \in \hat{\alpha} \qquad (6.3)$$

$\lambda_{k,n} \geq 0 \qquad n \in \hat{\alpha}$ (6.4)

where Φ denotes a scalar showing by how much the firms can increase output; $y_{k,m}$ denotes the output *m* by farm/firm *k*; $x_{k,n}$ denotes the input *n* used by farm/firm *k* and z_k are weighting factors. Inputs comprise of fixed factors and variable factors defined by the set as $\hat{\alpha}$. To calculate the capacity output measure, relaxing of the bounds on the sub-vector of variable inputs $x_{\hat{\alpha}}$ is required. Relaxing the bounds on the sub vector is achieved by allowing the inputs to remain unconstrained through introducing a measure of the input utilising rate ($\lambda_{k,n}$), estimated in the model for each firm *k* and variable input *n* (Färe et al., 1994). The technically efficient capacity utilisation (TECU) based on observed output (*u*) becomes:

$$TECU = \frac{y}{y^*} = \frac{y}{\phi_1 y} = \frac{1}{\phi_1} \qquad (6.5)$$

where *y** denotes the capacity-output based on observed outputs *y*. The TECU measure ranges from zero to one, with one implying full capacity utilisation (i.e. 100% of capacity) which assumes efficient use of all the inputs exists at their optimal capacity. Efficiency measures of less than one indicate that the firm operates at less than full potential given the fixed set of inputs. The input-oriented technical efficiency is given as follows:

$\mathrm{Min}\ \theta, \lambda\ \phi,$

Subject to:

$$-\mathrm{yi} + \mathrm{Y}\lambda \geq 0, \qquad (6.6)$$

$$\phi\,\mathrm{xi} - \mathrm{X}\lambda \geq 0, \qquad (6.7)$$

$$\mathrm{zi} - \mathrm{Z}\lambda \geq 0, \qquad (6.8)$$

$$\mathrm{N}1\text{‘}\lambda = 1 \qquad (6.9)$$

$$\lambda \geq 0 \qquad (6.10)$$

where, 1/ ϕ is the technical efficiency value which ranges between 0 and 1. Technical efficiency of a firm is achieved if ϕ =1 and vice versa. N1' denotes the convexity constraint which indicates a N×1 vector of ones and λ denotes a N×1 vector of weights which define the linear combination of the peers of the ith DMU. The nondiscretionary inputs are denoted by the L×1 vector zi for each farm/firm and the L×N matrix Z for the whole sample size and it implies that maximisation is achieved with the sub vectors that have only discretionary inputs.

6.2.2 Cost and allocative efficiency

The cost minimising problem for the ith DMU is the ratio of minimum cost to observed cost, expressed as:

$$Min_{\lambda x i*} W_i' X_i^* \tag{6.11}$$

subject to:

$$\sum_{i=1}^{n} \lambda_1 x_{j,i} - x_{j,i}^* \leq 0 \tag{6.12}$$

$$\sum_{i=1}^{n} \lambda_1 y_{k,i} - y_{j,i}^* \geq 0 \tag{6.13}$$

$$\mathrm{N}\,1\,‘\lambda \;=\; 1 \tag{6.14}$$

$$\lambda \;\geq\; 0 \tag{6.15}$$

where W_i denotes a transpose vector of the input prices for the ith DMU; X_i^* (calculated by the LP) denotes the ith firm's cost-minimising vector of the input quantity given the output levels y_{ki} and the input prices W_i. X_{ji} denotes input amounts while N1´ denotes the dual variables which are an N vector of ones. Thus, in the cost minimising framework, the total cost-efficiency (CE) of the ith firm is expressed as a ratio of minimum cost to observed cost as follows:

$$CE = \frac{W_i' X_i^*}{W_i' X_i} \tag{6.16}$$

Allocative efficiency is computed residually by calculating the ratio of the cost-efficiency to technical efficiency as follows:

$$\mathrm{AE} = \frac{\mathrm{CE}}{\mathrm{TE}} \tag{6.17}$$

Thus, a firm achieves cost-efficiency if it operates on the frontier and achieves allocative efficiency if it combines its inputs optimally given their prices.

6.2.3 Meta-frontier analysis

The concept of measuring efficiency using meta-frontier was first developed by Hayami and Ruttan (1970), and extended by Rao et al. (2003). The meta-frontier evaluates the efficiency of firms/units that operate under different production technologies or physical environment (climate, soil type and farming history). Several studies employ the meta-frontier to evaluate technical efficiency and establish if there any technological gaps among firms operating under different production technologies in areas such as manufacturing (Rao et al., 2003; Battese et al., 2004); agriculture (Rao et al., 2008); tourism (Assaf et al., 2010) and environment (Yang, 2010; Oh, 2010; Sala-Garrido et al., 2011).

The meta-technology as defined by Rao et al. (2003) is the total of the regional technologies. For example, if some output denoted by y, can be produced using an input quantity x in any given region, then x, y will belong to the meta-technology denoted as T^*. The meta-technology then will be expressed as follows:

$T^* = ((\mathrm{x}, \mathrm{y}): \mathrm{x} \geq 0$ and $\mathrm{y} \geq 0$, such that x inputs will yield y outputs using at least one region specific technology, $T^1, T^2, \ldots \ldots \ldots \ldots .., T^K)$ (6.18)

The meta-technology is assumed to satisfy all the production axioms and the convexity axiom, expressed as the convex hull of the pooled region-specific technologies as follows:

T^* ≡ Convex Hull $(T^1 \cup \ldots .. T^2 \cup \ldots \cup T^K)$. (6.19)

If the input-output distance function is known such that $D_0^*(\mathrm{x}, \mathrm{y})$ and $D_i^*(\mathrm{x}, \mathrm{y})$ denote for the output and input functions respectively using the meta-technology T^*then the results of any given region should be as follows:

$D_0^k(\mathrm{x}, \mathrm{y}) \geq D_0^*(\mathrm{x}, \mathrm{y}), \mathrm{k} = 1, 2, \ldots \ldots \ldots \mathrm{K})$ and $D_i^k(\mathrm{x}, \mathrm{y}) \leq$ and $D_i^*(\mathrm{x}, \mathrm{y})$. (6.20)

Thus, the output oriented technology gap ratio between the region k technology and the meta-technology is computed as follows:

$TGR_0^k(x, y) = \frac{D_0^*(\mathrm{x}, \mathrm{y})}{D_0^k(\mathrm{x}, \mathrm{y})}$ (6.21)

The technology gap ratio when considering the output-oriented technical efficiency measure is denoted as follows:

$$TGR_0^k\ (x, y) = \frac{TE_0^*(\mathrm{x,y})}{TE_0^k\ (\mathrm{x,y})} \tag{6.22}$$

or: $TE_0^*(\mathrm{x,y}) = TE_0^k\ (\mathrm{x,y}) * TGR_0^k\ (x, y)$ (6.23)

Figure 6.1 shows the relationship among three regional frontiers (1, 2 and 3 curves), the metafrontier (M curve) and the technology gap ratios.

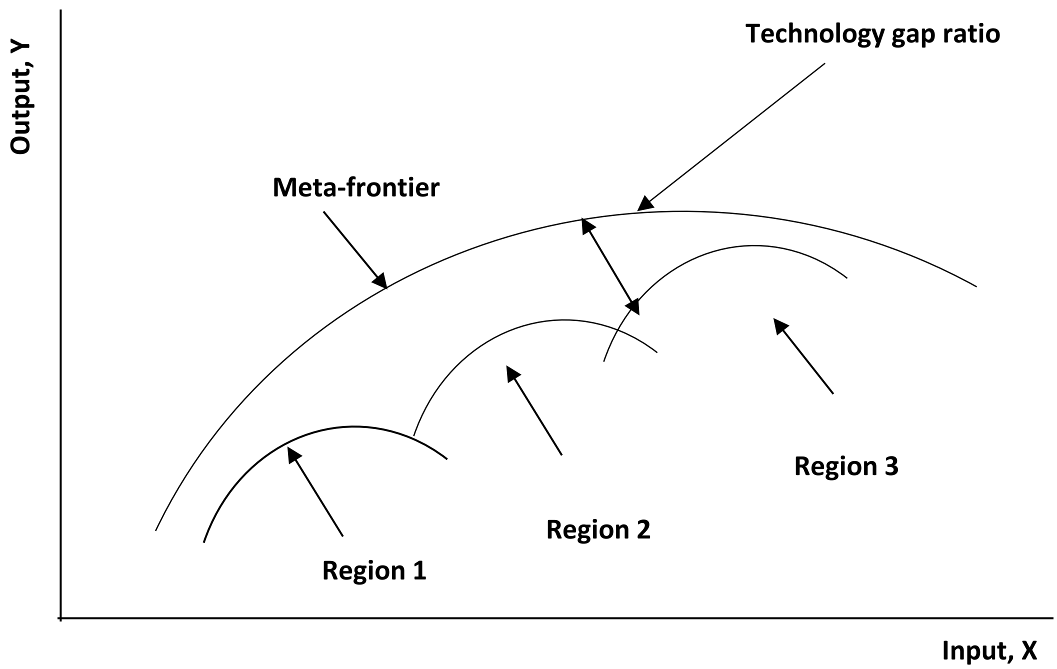


Figure 6.1 Technical efficiencies and Meta-technology ratios

6.3 COMPUTING EFFICIENCY USING THE NETWORK DEA METHOD

DEA is widely recognised and accepted as a major frontier technique in the analysis of multi-output production processes, hence providing a valuable analytical research tool for benchmarking many sectors. Although the standard DEA provides a useful description of the technology, it fails to describe the sub-technologies that make up its internal functions, which limits the use of DEA in some aspects. Standard DEA treats sub-technologies as a ‘black box’ and so does not provide information about what happens inside, thus failing to examine explicitly the inputs allocated and intermediate products that together form the production process. The network DEA model examines individual stages of production hence identifying any inefficiencies that the standard DEA model misses. Using network DEA to measure efficiency provides more meaningful and informative results given it considers how the component processes operate.

Network DEA has more recently been accepted as a tool which provides insights into specific sources of operational inefficiencies in a firm in areas such as banking (Avkiran, 2009; Fukuyama & Weber, 2010; Akther et al., 2013); education (Lee & Worthington, 2015; Fukuyama et al., 2015); transport (Yu & Lin, 2008; Duygun et al., 2015); management (Mirhedayatian et al., 2014; Lin, 2010; Vaz et al., 2010; Tone & Tsutsui, 2009). Notably, in the agri-food process, no study has evaluated the organisational process inefficiency of firms using the network DEA.

In the thesis, a two-stage process network DEA is therefore used to compute the technical efficiency of the rice milling businesses, with the results evaluated against the conventional DEA approach, i.e., the 'black-box' approach. The conventional DEA and network DEA methods in this study use the slack-based measure (SBM) to assess the performance of the mills. The network DEA approach will assess technical efficiency using a two-node process with the first node evaluating the drying part and the second node examining the milling part as shown in Figure 6.2.

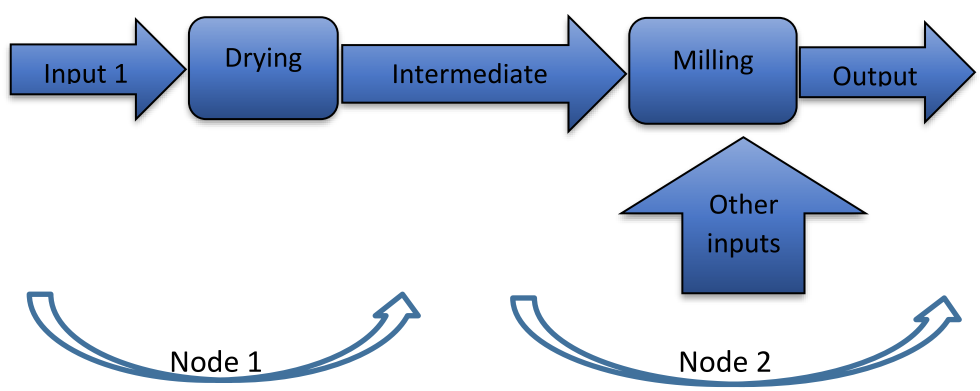


Figure 6.2 Structure of network DEA model for rice processing (two-node process)

Efficiency scores for each node are evaluated following the framework developed by Tone and Tsutsui (2009).

Assume n DMUs $(j = 1, \dots \dots, n)$, consisting of k nodes or divisions $(k = 1, \dots \dots, K)$ with m_k inputs and r_k outputs which go to nodes (division) k. The link connecting one node or division (k node/division) to the next node or division (h node or division) is denoted by (k,h). When they are many nodes or divisions they form a set of links denoted by L which finally link the intermediate products from one node to the next.

The inputs to node (division) k will be denoted as:

$$\{X_j^k \in R_+^{m_k}\}(j = 1, \dots \dots n; k = 1, \dots \dots K) \qquad (6.24)$$

The outputs to node (division) k will be denoted as:

$$Z_j^{k,h} \in R_+^{t_{(k,h)}}\} \; (j = 1, \dots, n; (k, h) \in L) \qquad (6.25)$$

where $t_{(k,h)}$, denotes the number of links while the production possibility set $\{(X^k, y^k, Z^{(k,h)})\}$ is defined as follows:

$$X^k \geq \sum_{j=1}^{n} X_j^k \lambda_j^k \qquad k = (1, \dots \dots .., K), \qquad (6.26)$$

$$y^k \leq \sum_{j=1}^{n} y_j^k \lambda_j^k \qquad k = (1, \dots \dots .., K), \qquad (6.27)$$

$$z^{(k,h)} = \sum_{j=1}^{n} z_j^{(k,h)} \lambda_j^k \qquad (\forall (k, h)) \text{ (as outputs from k)}, \qquad (6.28)$$

$$z^{(k,h)} = \sum_{j=1}^{n} z_j^{(k,h)} \lambda_j^h \qquad (\forall (k, h)) \text{ (as inputs to h)}, \qquad (6.29)$$

$$\sum_{j=1}^{n} = 1 \; (\forall k), \qquad \lambda_j^k \geq 0 (\forall j, k). \qquad (6.30)$$

where $\lambda^k \in R_+^n$ denotes the intensity vector corresponding to node (division) k (k = 1,……., K).

The input-oriented model is utilised to compute the technical efficiency scores given that an inefficient rice mill would appropriately improve performance by decreasing its input use rather than expanding their outputs. For example, the amount of paddy harvested from a given area is limited and hence reducing the labour usage for drying would be more logical than expanding paddy output. Again, from a given amount of paddy, only a certain quantity of rice would be obtained during milling. Hence looking at the input usage becomes more meaningful. The technical efficiency scores obtained are useful for comparing a DMU's total productivity with others. The measure provides useful insights for managers and the regulatory agencies into the improvement of efficiency since comparing DMUs from the firm level point of view becomes simpler.

Thus, the input-oriented efficiency of DMU_0 (0 = 1,…….n) is evaluated by solving the following linear programs:

$$\theta_0^* = \min_{\lambda^k, S^{k-}} \sum_{k=1}^{k} w^k \left[1 - \frac{1}{m_k}\left(\sum_{i=1}^{m_k} \frac{S_i^{k-}}{x_{i0}^k}\right)\right] \quad (6.31)$$

Subject to:

$$x_0^k = X^k \lambda^k + S^{k-}, \qquad k = 1, \ldots\ldots.. K, \quad (6.32)$$

$$y_0^k = Y^k \lambda^k - S^{k+}, \qquad k = 1, \ldots\ldots.. K, \quad (6.33)$$

$$e\lambda^k = 1, \qquad k = 1, \ldots\ldots.. K \quad (6.34)$$

$$\lambda^k, S^{k-}, S^{k+} \geq 0, \qquad (\forall k) \quad (6.35)$$

where

$$X^k = (x_1^k \ldots\ldots, x_n^k) \in R^{m_k xn} \quad (6.36)$$

$$Y^k = (y_1^k \ldots\ldots, y_n^k) \in R^{r_k xn} \quad (6.37)$$

The two processes are linked through constraints that are freely determined while keeping continuity between the inputs and the outputs (Tone, 2009) as follows:

$$Z^{(k,h)} \lambda^h = Z^{(k,h)} \lambda^k, \qquad (\forall (k,h)) \quad (6.38)$$

where,

$$Z^{(k,h)} = z_1{}^{(k,h)}, \ldots\ldots\ldots (z_n{}^{(k,h)}) \in R^{t_{(k,h)} xn}. \quad (6.39)$$

where λ, denotes the intensity vector and $\sum_{j=1}^{n} \lambda = 1$ denotes the convexity model under the variable returns to scale assumption. $\sum_{k=1}^{k} w^k = 1$, $w^k \geq 0$ $(\forall k)$ and w^k are non-negative relative weight measure for each node or division which add up to 1. The weights were set using an equal weight of 0.5 for each sub-process considering the importance of each node. A DMU is said to be full efficient if θ_0^* equals to 1, a condition equivalent to the optimal input (output) slack vectors denoted as S^{k-}or S^{k+}being equal to zero meaning that the input (output) shortfall or excess does not exist in the processes.

The input-oriented of each node or division evaluated using the optimal input slacks S^{k-} is defined as follows:

$$\theta_k = 1 - \frac{1}{m_k}\left(\sum_{i=1}^{m_k} \frac{s_i^{k-*}}{x_{i0}^k}\right) \quad (6.40)$$

where θ_k denotes the efficiency score for each node or division from which the overall efficiency θ_0^* is optimised with a node or division said to be fully input efficient if $\theta_k = 1$. Thus, the overall input-oriented technical efficiency scores are calculated by computing the weighted arithmetic mean of the efficiency scores of the divisions which is defined as follows:

$$\theta_0^* = \sum_{k=1}^{K} w^k \theta_k \quad (6.41)$$

6.4 DETERMINANTS OF EFFICIENCY

The standard methodology for investigating the technical efficiency determinants of a firm is to use the traditional DEA approach, which involves generating the efficiency scores in the first stage followed by determinants evaluation in the second stage. Thus, in the second stage, the efficiency score becomes the dependent variable and hence are regressed on covariates using the standard logit, probit models and truncated regressions. Studies that estimate determinants of efficiency by regressing efficiency scores on some covariates mostly specify a censored (tobit) model or a linear model based on ordinary least squares (see Aly et al., 1990; Chirikos & Sear 1994; Ray, 1991; Sexton et al., 1994; Cazals et al., 2002; Stanton, 2002; Daraio & Simar, 2005; Hoff, 2007; Banker & Natarajan 2008).

However, running a two-stage DEA is often criticised because the efficiency scores by nature are bounded at unity from above, which makes it a limited dependent variable. Modelling of such bounded variables especially the non-binary ones with many observations at the extremes thus becomes a challenge since it makes the application of the standard linear models inappropriate**.** The logit and probit models provide a limited approach to solving the problem due to their strong distribution assumption for the underlying population. Tobit regressions become appropriate when the dependent variable is limited either above or below and when unbounded elsewhere. However, the two-limit tobit model does not observe efficiency scores of zero which implies that the estimates end up being based on the one limit tobit (Ramalho et al., 2010).

Recent developments in the two-stage process include the use of the bootstrapping technique which assumes that the accumulation of observations at unity is due to censoring (see Simar & Wilson, 2007). However, McDonald (2009) argues that efficiency scores being fractional data, may not be generated by a censoring process. McDonald (2009) adopts the 'conventionalist' approach in evaluating the two-stage process where the efficiency scores are measured relative to an estimated frontier. However, the approach fails to solve the sampling variation issue. An approach adopted by Banker & Natarajan (2008) that assumes a linear correlation exists between the logged technical efficiency scores and the covariates seemed favourable. However, the method only considers one parameter estimates and does not tackle the issue of hypothesis testing of the estimated variables.

The fractional regression model (FRM) developed by Papke and Wooldridge (1996) represents a viable solution to addressing the challenge of the second stage DEA analysis. The FRM is a class of functional forms extended from the general linear model. FRM has the following advantages: first, it helps to cater for the boundedness of the dependent variable from above and below. Second, it helps predict response values within the interval limits of the dependent variable and last, it captures nonlinear data thus yielding better estimates. The only assumption required of FRM is a functional form of y to impose the desired constraints on the dependent variables (Ramalho et al., 2010) as follows:

$$E(y|x) = G(X\theta) \tag{6.42}$$

where $G(.)$ denotes a nonlinear function that satisfies the condition $0 \leq G(.) \leq 1$.

The model is estimated using four widely accepted models which include the logit, probit, loglog and complementary log referred to as Cloglog. The partial effects in all the models are denoted as:

$$\frac{\delta E\ (y|x)}{\delta x\mathrm{j}} = \theta_{jg}(x\theta) \tag{6.43}$$

In the recent works of Ramalho, et al. (2010), the authors recommend use of the fractional regression models to analyse efficiency determinants in the second stage. They consider a one and two-part models due to the differences in efficiency scores. The one-part models assume that:

$$E\left(\hat{\theta}\middle|w\right) = G(w\delta), \tag{6.44}$$

where G(.) denotes a probability distribution function. δ is unknown and is estimated by quasi-maximum likelihood (QML) that maximises:

$$\textstyle\sum_{i=1}^{n}(\,\hat{\theta}_i \log(G(w_i\delta))) + (1-\theta_i)\log\bigl(1-G(w_i\delta)\bigr). \tag{6.45}$$

In the two-part models the whole sample is used to estimate the model:

$$Prob\ \left(\hat{\theta}_i = 1\middle|w_i\right) = F(w_i'\beta) \tag{6.46}$$

where β is an unknown parameter and F is a known probability distribution function. It is assumed that $\left(\hat{\theta}_i\middle|w_i\right) = G(w_i'\delta)$ for the responses in (0, 1) for the second part.

The technical efficiency scores of the milling and drying process were computed using the Max DEA Pro 6.0 while the efficiency determinants were evaluated using the FRM models based on codes of Ramalho, et al. (2010) in programming language R version 2.15.2 respectively. In the first stage (drying sub-process), the efficiency scores were regressed against the following determinants: miller's age, miller's experience, miller's gender, storage area and market distance. In the milling-sub-process (second stage), the efficiency scores were evaluated against the following variables: miller's experience, miller's years of schooling, the number of times the mill is serviced, age of the mill (number of years used) and energy type. A positive variable sign implied that the variable was positively affecting efficiency and vice versa.

6.5 STUDY SITE

6.5.1 Introduction

The data used for analysis came from a field survey of four sites in Kenya i.e. Mwea, Bunyala, Ahero and West Kano schemes. The four sites were chosen given that rice was the predominant crop grown in the schemes. The schemes together supply almost 90% of the rice sold in the Kenyan market, and represent different agroecological conditions under which rice is grown in Kenya.

This section describes the study areas. Sections 6.5.2 and 6.5.3 provide information about Mwea and the Western Kenya schemes (Bunyala, Ahero and West Kano), respectively.

6.5.2 Mwea irrigation scheme

The Mwea irrigation scheme is situated in the Kirinyaga County, which is about 100km from the capital city, Nairobi. Mwea remains the biggest paddy rice producing system in Kenya, with 50% of its area being used for irrigated rice growing, while the remaining space is under small-scale farming, and used for grazing and community events such as sports.

The scheme was initiated in 1956 by the African Lands Development (ALDEV) department of the British colonial regime, with rice being the only predominant crop. The scheme's goal was not only to provide food for the British troops, but also contain Kenyans agitating for land occupied by the European settlers. Free detainee (Mau-Mau) labour was thus used to construct the rice irrigation infrastructure.

In 1963 when Kenya gained its independence, the new government started managing the scheme through the ministry of agriculture which focused on rice growing under land tenancy agreements. Thus, the National Irrigation Board (NIB) was enacted in 1966 and given the mandate to develop, improve and manage the national rice schemes. By mid-1970s, three other Western Kenya schemes were established, i.e., Ahero, Bunyala and West Kano to augment food crop supply and hence reduce the relief food supply burden. The NIB oversaw rice growing by being involved from the preparation of paddy fields, providing inputs and through to paddy marketing.

Since the farmers had no say in how the paddy price was being set and with their growing resentment over the low paddy price offered by NIB, they formed their own company, Mwea Rice Growers Multipurpose Society (MRGMS), in 1988, to take over the NIB services. However due to lack of technical and rice infrastructure expertise the MRGMS faced the challenge of running the scheme efficiently. In 2003 the farmers requested the NIB to provide infrastructure and the required technical skills to run the scheme through a partnership. The partnership adopted the Participatory Irrigation Management (PIM) model whereby all the partners had a say in the running of the scheme. Thus, the MRGMS took up land preparation, input and marketing support activities, the IWUA manages water distribution, and the NIB provides technical and infrastructure expertise services.

The Mwea scheme draws its water from the Nyamindi and Thiba rivers through gravitational force. The two rivers are linked together by a central canal, with each rice block or unit having a smaller feeder and canal which serves all farmers. The Nyamindi river serves Tebere, Ndekia, Kiamanyeki and Kianugu units while the Thiba river serves Mwea, Thiba, Wamumu, Marura, Karaba and out-growers of the Mutithi/Curukia units. The average temperature of Mwea range between 23°C and 25°C, with a difference of about 10°C between the minimum and maximum temperatures which are experienced in June/July and October/March respectively (Ijumba *et al.,* 1990; Mutero *et al.,* 2000). The average annual precipitation for Mwea is 950 mm.

The scheme currently has a gazetted area of 30,350 acres, with a total of 16,000 acres already developed for paddy production and an addition of 4,000 acres under out-grower and jua kali production. The Mwea Irrigation Scheme has about 6000 rice farmers. There are two groups of land leases. The first is the freehold owners who are known as out-growers who emerged after the rice market liberalisation in 1988. The out growers occupy Ndekia, Mutithi and Kiamanyeki areas and hold title deeds to the land. The leaseholders have a land lease for 99 years from the government with each tenant holding at least 4 acres of the land. However due to population pressure, subdividing the land among family members and in other cases, transferring to new farmers, has become common thereby reducing the average rice acreage. Under the leasehold system, the National Irrigation Board controls the rice expansion and the cropping calendar/system.

Source: National Irrigation Board (NIB), Mwea

Figure 6.3 Map of Mwea Irrigation Scheme

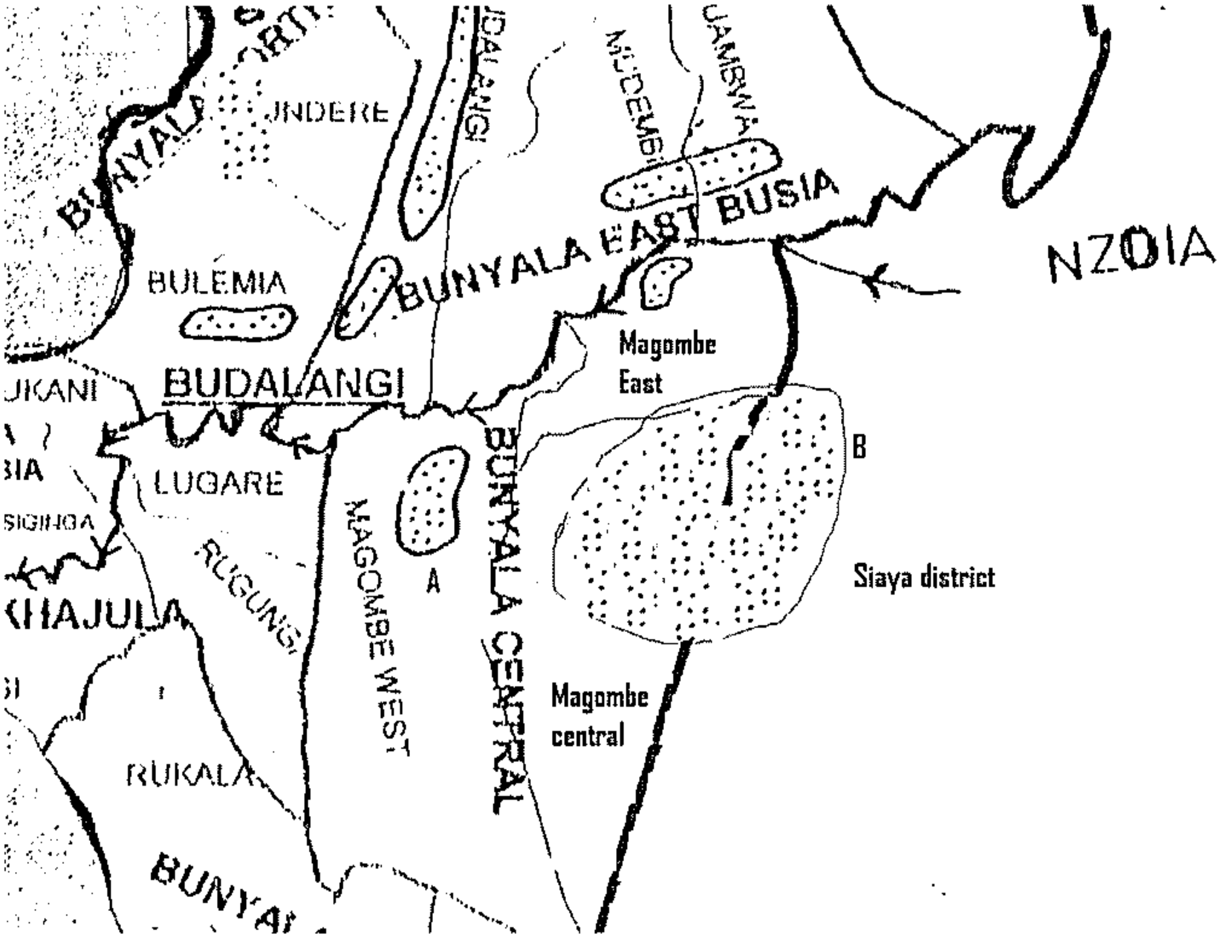
6.5.3 Western Kenya rice irrigation schemes

The Western Kenya has three irrigation schemes, namely, West Kano, Ahero and Bunyala, all under the management of the NIB. The National Irrigation Board provides the irrigation and other technical services while the farmer organisations handle the inputs and water distribution through the WUA. The rice schemes are characterised by bimodal rainfall patterns with an average rainfall of 1175mm. The temperatures across the schemes ranges from 22.1^{0}C and 23.5^{0}C. The soils are black cotton which are characterised by high clay content. The common rice variety grown in the three schemes is Sindano (IR2793) with Basmati 370, ITA 310 and BW 196 also being grown. Each farmer is licensed to grow rice on four plots of 0.4ha, with a total acreage of 1.6ha per farmer. Marketing of rice is done through the farmer organisations marketing committees, which sell the paddy to the National Cereals and Produce Board (NCPB), the Lake Basin Development Authority (LBDA), Western Kenya Rice Mills Company, Capwell Industries Ltd, local millers or traders and to individuals from the neighbouring countries, especially Uganda. Farmers receive up to Ksh.7000 per 80kg bag of paddy during the low rice season.

The Ahero and West Kano irrigations are situated on the Kano Plains, Kisumu County. The Ahero Irrigation Scheme was commissioned in 1969 and collapsed in the year 2000. The scheme was revived in 2005 to support approximately 520 farmers on an 840-acre net irrigated area which has since expanded to more than a thousand hectares supporting a total of 819 rice farmers. The farmers have benefited from the FAO input grants and the government economic stimulus programme (ESP). The scheme draws its water from River Nyando using electrically operated pumps. The West Kano Irrigation Scheme occupies the area between the Nandi Escarpment and the Nyabondo Plateau on the shores of Lake Victoria. The scheme was commissioned in 1975 but collapsed in the year 2000 and was later revived in 2003 with the phase one crop covering 1158 of the 2229 acres. The scheme currently has 790 small-scale farmers. The water intake comes from Lake Victoria using electrically operated pumps.

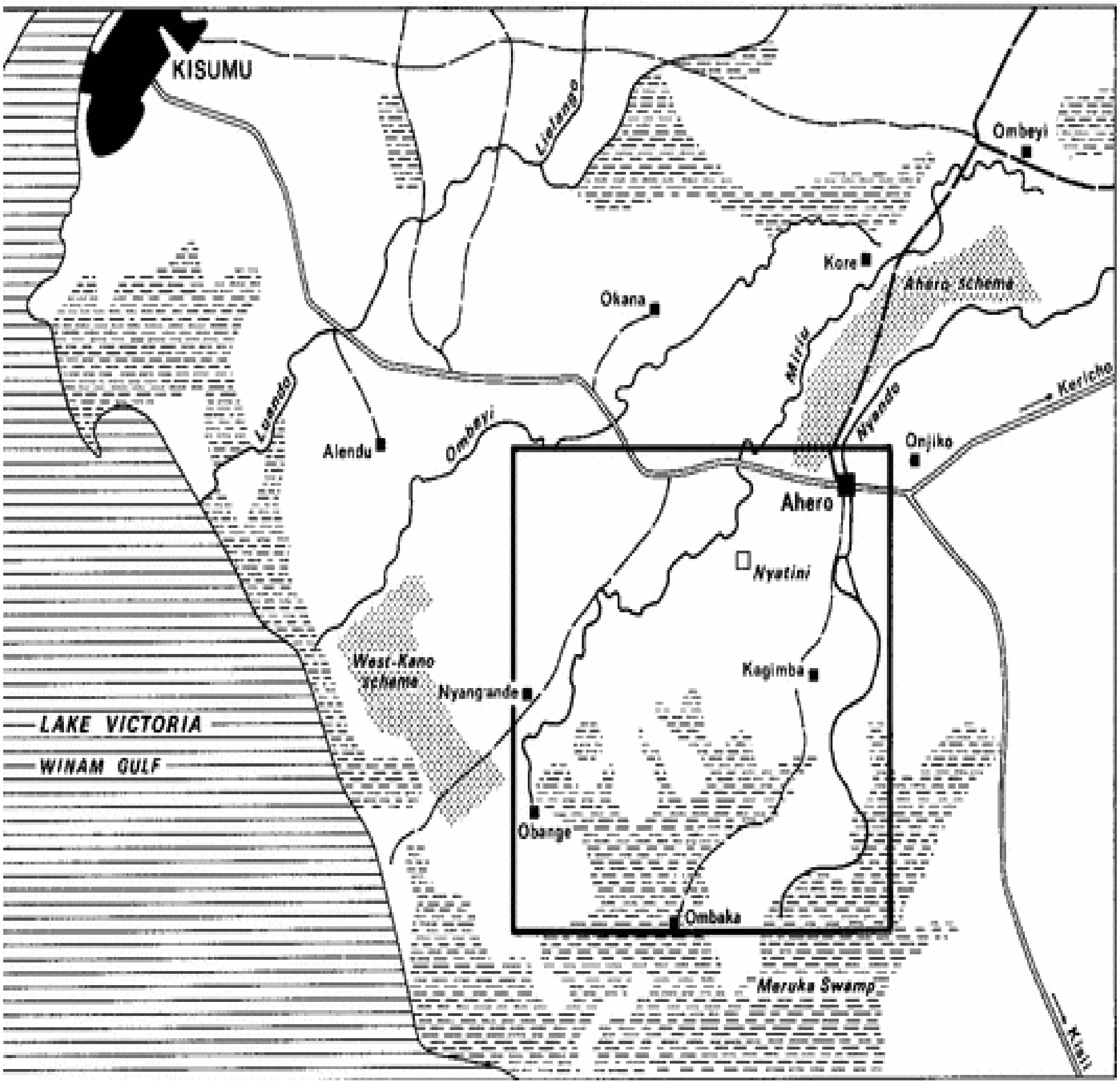
The Bunyala irrigation scheme is in Bunyala Central, Busia County, and the Usonga area of Siaya County. The scheme draws its water from the Nzoia river using electrically operated pumps. The scheme was commissioned in 1968 but collapsed in the year 2000 and was later revived in 2004. The scheme has a gazetted area of 1734 acres although only 534 acres is utilised by 133 rice farmers with a target of expanding the paddy area by a further 1363 acres. The Magombe Co-operative Multipurpose Society takes care of the inputs and marketing aspects. The Co-operative started in 1969 and provides rice farmers with savings and credit services, advance pay, marketing and inputs such as fertiliser and seed. The rice farmers deliver to the Magombe Cooperative Multipurpose Society between 12000 and 20000 bags of harvested paddy.

The challenges faced by the farmers in the three schemes include delay in watering the paddy fields for planting due to the unreliable electrically-powered irrigation system, delay in receiving planting seed from Mwea, lack of appropriate machinery for undertaking operations such as planting, harvesting, drying or transporting of paddy, high costs of inputs, competition from neighbouring Ugandan rice farmers, high waterborne diseases, lack of water storage for use especially during the dry season and poor networking among the rice farmers.



Source: Bunyala Irrigation Scheme

Figure 6.4 Map of Bunyala Irrigation Scheme



Source: Ahero Irrigation Scheme

Figure 6.5 Map showing location of Ahero and West Kano irrigation schemes

6.6 ETHICAL CONSIDERATIONS

The field work survey instruments and process was scrutinised by the QUT Human Research Ethics Committee and then assigned approval number 1400000195 (see Appendix J) after meeting the ethical requirements of the Australian *National Statement* on Ethical Conduct in Human Research (2007). The national statement consists of the guideline series approved in line with the *National Health and Medical Research Council Act 1992.*

As inconveniencing the respondents was the only foreseeable risk with no risk of harm or discomfort associated with participating in the research interview anticipated, the research was classified as low risk. However, the benefits outweighed the risk since the research findings would propose policies aimed at increasing rice output and at improving rice processing efficiency in Kenya. As enumerators kept to the questionnaire content and minimised the time spent, the danger of inconveniencing the farmers or millers was minimised.

6.7 SAMPLING AND DATA COLLECTION

6.7.1 Rice farmers

The target population consisted of adult (over 18 years) small-scale rice farmers located in Mwea and Western Kenya (Ahero, West Kano and Bunyala) rice schemes. The primary data used was from a household survey conducted in these rice regions. Conducting a survey was preferred given secondary sources would not have provided all the data required for the study. Furthermore, surveys are widely accepted as a legitimate means to collect data on areas such as unemployment rates, peoples' income and expenditure, health conditions, criminal events, agriculture production and transport systems (Fowler Jr, 2013).

Using the sampling framework of Krejcie and Morgan (1970) a sample of 835 small-scale rice farmers was drawn from the four rice schemes of Kenya. The survey involved area probability sampling which remains one of the most useful multistage strategies widely applied when obtaining a sample from any geographically defined population (Fowler Jr, 2013). The sampling stages involved first mapping the scheme units in each area and then randomly selecting the target survey units. The respective National Irrigation Board provided a map and list of the rice blocks for sampling.

In Mwea (see Figure 6.2), twenty-five rice farmers were randomly selected from twenty rice blocks (rice villages), making a sample total of 500 farmers. Mwea has about 6000 rice farmers thus making a sampling ratio of 8.3%. The rice schemes of western Kenya consist of Ahero, West Kano and Bunyala irrigation schemes. Due to the less number of farmers in the western schemes, a higher sample proportion was drawn from these areas. The Bunyala scheme (see Figure 6.3) has 133 farmers divided into seven blocks, hence a sample of thirty-five farmers was obtained making a sampling ratio of 26.3%. The West Kano scheme and Ahero schemes (Figure 6.4) have twelve rice blocks each with a total of 819 and 1650 rice farmers respectively. A sample of 140 and 160 rice farmers was obtained from the West Kano and the Ahero schemes respectively thus making a sampling ratio of 17.1% and 9.7% respectively.

The first survey took place in Mwea between mid-April and the end of May 2014, and was later extended to the three western Kenya schemes during the month of June. Finalising field work arrangements took place during the first week of April 2014 and which included seeking support from relevant rice authorities and the respective area National Irrigation Boards. The support process involved holding a meeting with the scheme managers and staff, and providing them with information about the fieldwork and its purpose. The National Irrigation Board gave approval for the fieldwork as per the letters endorsed by the respective rice scheme managers (see Appendix K).

Enumerators used in conducting the survey (pretesting and actual surveys) were recruited from each region based on their academic qualifications, field work experience and familiarity with rice farming practises. The minimum educational requirement of an enumerator was a bachelor's degree. However, those with lesser qualifications such as a diploma or certificate in agriculture but with relevant fieldwork experience were also considered. Mwea region had a total of five enumerators, and one project assistant;

Ahero and West Kano areas had three enumerators respectively while Bunyala had two enumerators. Preparing the enumerators for the fieldwork involved holding a briefing session followed by a one-day training on the survey. The enumerators' training covered how to administer a survey in general and which included the following aspects: how to approach the respondent, physical appearance, the tone of voice, the wording of questions, probing strategies in case of incomplete answers, limiting unstructured discussion and how to record the respondents' answers to the questionnaire. To maintain confidentiality during the survey, the enumerators signed a confidentiality agreement form as approved by the QUT code of ethics and practises (see Appendix L).

The data was collected using a questionnaire in both English and the national language, Swahili. Developing the questionnaire heavily relied on previous literature and in line with the objectives of the study. Using a sample of 30 questionnaires, pretesting was carried out using farmers in the Mwea scheme. This was in line with professional survey organisations which typically conduct pretesting by holding 20 to 50 interviews with respondents drawn from the same or a similar target population (Fowler Jr, 2013). Pretesting was necessary for three key reasons. First, it evaluated whether the questionnaire was well understood by the enumerators and the respondents, and if the respondents provided meaningful answers. Second, it tested the enumerators' data collecting skills and the adequacy of all the steps involved in the data generating process. Last, it ensured consistency in selecting the indicators and the data collection design. An examination of the pretested questionnaires revealed no issues of concern thus allowing it to be adopted as the final questionnaire.

Enumerators conducted face to face interviews in each scheme to collect the data. The interview process involved first giving the respondents the information sheet which outlined the purpose of the survey, the survey content and the sponsoring agency so that they could make an informed judgment about whether they would participate in the study or not (see Appendix M). Second, the participants were informed that taking part in the survey was voluntary, that they had a right to withdraw at any time without notice. Third, the respondents were assured that answering all questions was not mandatory, hence if they did not wish to answer any specific question, they had a right of omission. Finally, the participants were assured that all information they provided would remain confidential. Thus, the actual interviews went ahead after those willing to participate in the survey signed a consent form of which they retained a copy (see Appendix N).

Each farmer interview and recording of data in the questionnaires took at least forty-five minutes to complete with each enumerator administering an average of five questionnaires per day. Face to face interviews proved advantageous since they provided a higher response rate and provided ease of clarification to any questions that the respondents did not understand. However, face to face interviews turned out to be costly and required factoring in of travel time between interviewing locations the need for supervision and required the enumerators to handle the interview skilfully (Neuman, 2009). Having a project assistant helping in supervising the interview process and through recording some of the actual interviews helped minimise the potential risks of the survey. The funding provided by Australia Awards Africa covered all the fieldwork costs which included enumerator costs, travel expenses, communication expenses, data entry and incidentals (see section 6.8).

The data collected from the rice farmers' interviews and recorded in the questionnaires (see Appendix O) included output data (i.e. paddy amount harvested), input data and unit cost of fertiliser, labour, seed, pesticides and land area (number of hectares planted). The data collected on socio-economic characteristics included farmers' age, farmer gender, household size, years of schooling, rice farming experience, extension advice distance and market distance. The Kenya National Meteorological Department provided the regional rainfall data. Secondary sources such as reports and websites supplemented the survey with further data on humidity and temperature.

The data clerk keyed in data from the completed questionnaires in excel sheets followed by data cleaning by the researcher which included cross-checking the accuracy, completeness and consistency of the data with the questionnaires. During the data cleaning process, some observations were dropped due to missing key variables such as outputs or inputs or due to the ratio of their total outputs and inputs varying excessively.

Respectively 17, 13, 29 and 3 observations for Mwea, West Kano, Ahero and Bunyala were dropped. Thus, the total sample used in this study was 773 after removing 62 (7.4%) observations.

6.7.1.1 Descriptive statistics of rice farmers' data

Table 6.1 provides summary statistics of the rice farmers' data. The statistics indicate that most farmers harvested an average of 4192kg of paddy per year, with a maximum of 28500kg and a minimum of 225kg. In terms of input quantities, land size ranged between 0.25 acres and 12 acres with an average of 1.98. On average farmers used 222.4kg of fertiliser, with a maximum of 2400kg and a minimum of 24Kg. On average, the farmers applied 0.76 litres of pesticides, with a maximum of 12 litres while a few farmers did not use pesticides. Given very few farmers did not apply pesticides, sample average estimates were used on the assumption that the effect the average had on the estimates was negligible. On average, farmers used 42.3kg of seed with a maximum and minimum of 330kg and 2kg respectively. Hired labour was on average 32.9 persons, with the maximum number being 178 while some farmers did not hire any workers. On average, farmers used 1.47 persons of family labour with a maximum of 23 persons per season. Thus, combining family and hired labour provided an average of 34.4 persons per season.

In terms of input prices, the paddy unit price ranged between 25Ksh and 100Ksh depending on the variety with an average of 46.1Ksh. The operations and maintenance costs (referred to as water expenses) served as a proxy for land cost per acre which on average was 2538.7Ksh. Dividing the total pesticide cost by the total pesticide quantity gave the pesticides unit cost which was on average 2.57Ksh. The unit cost of seed and fertiliser was 88.2Ksh and 53.6Ksh per kg on average respectively. The labour wage rate was estimated at 1284.4Ksh per head per season. This figure was used as it was difficult to quantify some operations on a per day basis such as nursery preparation or hallowing which take only a few hours to complete. Some activities were also paid on a fixed contract basis, hence wages per day rate did not apply. For analysis purpose, the average labour costs were used where farmers used family labour only.

The demographic attributes of rice farmers captured included rice farmer's age, which ranged between 20 and 88 years, with an average of 48.6 years. A dummy variable captured the farmers' gender with males' being assigned one and females zero: 551 farmers were male and 222 females. On average, farmers had 8.1 years of schooling with the maximum number of years of schooling attained being 19 years while the minimum being a few farmers not having formal education. On average, farmers had 18.5 years of rice farming experience with a maximum of 80 years and no experience as a minimum. The market distance served as a proxy for infrastructure. Farms on average were located at 3.9km away from the market with the farthest being 20 km away. On average, farms were located 4.1km from extension advice with the farthest being 28km away and the nearest being close to the NIB office. The average rainfall ranged between 980.9mm and 1717.6mm with an average of 1113.0mm. Average humidity was 69.03% with a minimum of 64.5% and a high of 71.3%. The mean temperature was 22.7^{0}C, with a minimum of 22.3^{0}C and maximum of 23.3^{0}C. To cater for the regional differences, a dummy variable of one was assigned for farms located in the Mwea region and zero for those located in other regions. A dummy variable represented technology adoption, with one if a farmer adopted SRI technology and zero if otherwise. 605 (78.3%) of rice farmers were conventional farmers and 168 (21.7%) were SRI farmers. MaxDEA 6.0 software was used to generate the efficiency scores.

Table 6.1 Descriptive statistics of inputs and outputs for rice farmers

Variable	Mean	Min	max	StdD
Paddy (kg)	4192.00	225	28500	3139.59
Size of plot (acres)	1.98	0.25	12	1.31
Total fertiliser (kg)	222.39	24	2400	192.01
Pesticide applied (L)	0.76	0.01	12	0.92
Seed quantity (kg)	42.33	2	330	33.78
Labour hired (No)	32.97	0	178	20.43
Family labour used (No)	1.47	0	23	2.95
Total labour (No)	34.44	1	178	20.41
Unit prices				
Price per unit of paddy	46.07	25	100	10.56
Cost of land = Water cost per acre	2538.65	300	14800	1091.18
Average fertiliser per kg (Ksh)	53.57	0	138	13.33
Average cost of pesticides (per unit)	2.57	0.02	150	7.42
Cost of seed per Kg	88.17	20	200	16.30
Wage rate per head (Ksh)	1284.50	145.82	11610	1437.96
Inefficiency estimates				
Gender (1= male, 0 otherwise)		0	1	
Age (years)	48.63	20	88	13.54
Schooling (years)	8.07	0	19	3.83
Household members (No)	5.36	2	28	2.87
Experience (year)	18.46	1	80	13.52
Distance to extension advice (km)	4.09	0.007	28	3.85
Distance to the market place (km)	3.89	0.01	20	3.26
Average rainfall (mm)	1112.99	980.934	1717.6	189.55
Average humidity (%)	69.03	64.5	71.3	1.76
Average temperature (^{0}C)	22.65	22.3	23.3	0.47
Region dummy (1= Mwea, 0= Otherwise)		0	1	
Technology (1 = Adopted, 0 = Otherwise)		0	1	

Source: Field survey estimates and other sources

6.7.2 Rice millers only

The Mwea region has the largest number of rice millers, with about 200 small-scale mills and five large mills, majority of which are privately-owned. The Mwea population draw their livelihoods from rice farming and milling, hence the rice millers remain a key player in the rice market accounting for about 80% of locally milled rice supply.

The study sampled 123 rice millers only (who milled paddy and charged a milling fee) out of the 150 Mwea rice millers surveyed through questionnaires (see Appendix P). The socio-economic characteristics in the questionnaires captured included: millers' age, gender, the number of household members, years of schooling, years of experience and market distance. The questionnaires also captured technology components included: mill type (if electricity or fuel operated), the age of the mill (number of years used), mill hours per day, the number of days the mill operated and the number of times the mill was serviced annually.

The total paddy milled represented the output per year. The variable and fixed input costs considered included the capital, labour and energy costs. The mill-specific pollutant emission indicators (carbon dioxide emissions from energy use) were calculated using the IPCC 2007 average index for Kenya of 0.306kgCO_2 emissions per energy kilowatt (IPCC, 2007). The energy used was converted to kWh equivalent using the energy conversion factor of 11.63 litres of fuel being equal to 1 electricity kilowatt (kWh).

Measuring the efficiency scores was effected in two ways; first by obtaining the traditional scores and secondly by generating the environmental scores (efficiency in the presence of carbon dioxide emissions) using the Max DEA 6.0 version. The efficiency determinants were evaluated using the fractional regression model.

The summary statistics of the data are provided in Table 6.2. The statistics indicate that most mills processed an average of 475,476.7kg of paddy per year with an average use of 15,079.3 Kilowatt-hours (kWh) energy equivalent being used per year. The average number of workers was on average 1.79 persons. Each mill operated for at least 1,704.9

hours a year on average. The carbon dioxide emissions from energy use were on average 4,614.3kg.

The input prices needed to solve the linear programme of the cost minimising DEA model included: the labour unit price per day, unit capital cost and unit energy cost. The total labour costs were used to calculate the labour unit price by dividing the labour costs by the number of workers and days worked. Thus, the labour unit price was on average 333.49 Ksh with average labour costs being applied to millers using family labour. Dividing the total energy cost by the total energy equivalent per year gave the energy unit price, which on average was 10.19 Ksh. The unit capital cost was on average 125.5Ksh obtained by dividing the mill book value (depreciated value of the mill) by the total number of mill hours per year.

The miller specific variables included the millers' age, which ranged between 20 and 70 years with an average age of 39.6 years. A dummy variable represented the millers' gender with one denoting for males and 0 otherwise. The millers' educational level was captured by the number of years of formal schooling, which ranged between 2 and 18 years, the average being 10 years. The millers' years of experience averaged 5.7 years with a range of 0 and 20 years. The age of the mill (number of years used) varied between 0.5 and 18 years with an average of 5.6. The frequency of mill servicing ranged between 0 and 52 times a year with an average of 17.3 per year. A dummy variable was used to represent the energy type with one denoting electricity and 0 otherwise. Only 116 rice millers remained in the study's final sample after dropping seven millers (5.7%) for either not having complete data or due to being outliers.

Table 6.2 Descriptive statistics of inputs and output for rice millers only

Variable	Average	Minimum	Maximum	Std. Dev
Total Paddy	475476.72	10400	6240000	702524.5
Energy equivalent (kWh)	15079.26	1814.28	72571.2	11706.66
Labour (No)	1.79	1	31	2.85
Machine hours (Hrs)	1704.94	312	7488	1073.5
CO_2 emission (kg)	4614.25	555.17	22206.79	3582.24
Energy cost/unit (Ksh)	10.19	8.60	20.22	1.87
Labour unit cost (Ksh/day)	333.49	27.69	1661.54	295.41
Capital cost unit (Ksh)	125.49	10.68	600.96	107.26
Inefficiency estimates				
Age (years)	39.59	20	70	10.18
Gender (dummy)		0	1	
Household members (No)	4.26	0	8	1.75
Education (years of schooling)	10.03	2	18	2.60
Experience (years)	5.71	0	20	4.15
Distance to market (km)	4.58	0.01	13	3.58
Age of mill (years used)	5.61	0.5	18	3.74
Frequency of servicing (No)	17.26	0	52	17.21
Fuel type (dummy)		0	1	

Source: Survey estimates
Note: Std.Dev = standard deviation and this definition applies to the preceding tables

6.7.3 Rice farmers/millers

The analysis used a sub-sample of 27 out of the 150 Mwea rice millers interviewed in June 2014. The millers' socio-economic characteristics utilised in the analysis included age, miller's gender, the number of household members, years of schooling, years of experience and the market distance. The technology characteristics included age of the mill (number of years in use), mill hours per day and number of mill servicing per year. The direct inputs captured included the amount of labour and fuel used. The inputs used included labour, capital and fuel and the paddy processed which represented the output. Only 26 DMUs were used in the final analysis after dropping one DMU (3.9%) due to its low family labour share compared with the other observations following the method of Tran et.al. (2010). The summary statistics of the inputs, outputs and environmental variables are presented in Table 6.3.

Outputs for nodes 1 and 2 included paddy and rice processed, respectively. Inputs for node 1 comprised of the number of workers for drying while node 2 inputs included: the number of workers, mill hours and energy equivalent. The environmental variables for node 1 included: millers' age, millers' experience, miller gender, storage space available and market distance. Node 2 environmental variables included: years of schooling, millers' experience, the number of mill servicing, the number of years the mill has been in use and energy type used. The average, paddy processed and rice milled obtained per year was 7,883,700kg and 6,095,548kg respectively. The average energy equivalent used for milling was 23,905.6kWh. The average number of workers used for milling was 6.7 persons. The average adult number of household members (representing the number of employees) used for paddy drying was 4.9. Since paddy drying is more often relegated to family labour than the milling process, the use of household members to capture drying labour was justified.

The miller-specific variables included the millers' age, which ranged between 20 and 65 years, with an average of 39.2 years. A dummy variable represented the miller's gender with 26.9% being male and 73.1% were female. The millers' education level was represented by years of schooling, which on average was 11.5 years, it ranged between 6 and 16 years. The millers' years of experience ranged between 2 and 25 years, with a mean of 7.8 years. The market distance (representing the state of infrastructure) varied between 110km and 5 metres, with an average of 5km. The paddy/milled rice storage space averaged 447.2 square metres. The age of the mill (number of years used) was on average 10.7 years and it ranged between 1.5 and 46 years. The mill servicing ranged between 1 service and 156 servicing per annum with an average of 26.4 servicing. The type of energy was captured using a dummy whereby one denoted electricity and zero otherwise. 76.9% of mills used electricity as the source of power.

The efficiency scores and its determinants were evaluated using the Max DEA Pro version 6.0 programme and the FRM framework based on the codes of Ramalho et al. (2010) in programming language R version 2.15.2 respectively.

Table 6.3 Descriptive statistics of inputs and output for rice farmers/millers

Variable	Average	Minimum	Maximum	Std. Dev
Inputs (node 1)				
Number of workers for drying	4.9	3.0	10.0	1.8
Inputs (node 2)				
No of machine hrs.	2,780.2	936.0	7,488.0	1,426.3
Energy equivalent (kwhs)	23,905.6	1,173.1	81,344.0	23,041.5
Number of workers for milling	6.7	1.0	45.0	10.4
Output (node 1)				
Total paddy (kg)	7,883,700.0	21,600.0	156,000,000.0	30,471,642.8
Output (node 2)				
Rice processed (kg)	6,095,548.0	12,984.0	119,000,000.0	23,219,999.3
Environmental variables				
Age (years)	39.2	20.0	65.0	10.5
Gender (dummy)		0.0	1.0	
School (years)	11.5	6.0	16.0	2.7
Experience (years)	7.8	2.0	25.0	6.0
Distance (km)	5.0	0.005	110.0	21.5
Storage (square metres)	447.2	0.0	5,400.0	1,166.2
Mill used (years)	10.7	1.5	46.0	9.6
Number of times mill serviced	26.4	1.0	156.0	32.9
Energy type (dummy)		0	1	

Source: Survey estimates

6.8 FUNDING

The Australia Awards Africa (AAA) funded the fieldwork through their research support fund for Australian Awards students undertaking fieldwork in Africa. The AUD$ 10,000 catered for all the field work expenses such as the travel costs, administering questionnaires, communication, data entry and stationery as shown in the budget in Appendix Q. The funding agency did not participate in the study design, collecting data or data analysis.

6.9 CHALLENGES FACED DURING FIELDWORK SURVEY

The field survey took place between April and June 2014 which was an off-season period when little rice farming activities took place, thus providing ample time for farmers to attend to the survey. The photos taken during the field work survey are as shown in Appendix R.

However, despite the above advantage, several challenges were faced during the fieldwork include. First, the questionnaire was long, taking about forty-five minutes to administer to farmers. The patience of farmers and expertise of the enumerators who kept the farmers engaged throughout the interviews helped in overcoming this challenge.

Second, the poor road network within the rice field survey sites sometimes made it difficult to navigate through with a motor vehicle. Using motorcycles and sometimes walking helped to overcome this problem.

Third, some farmers failed to understand the importance of signing the consent forms before the interview, while others were reluctant largely due to previous bad experiences with signing other consent forms. This was overcome by the researcher assuring farmers that the consent forms were part of the research ethics process which the survey had to conform to and by signing the forms it ensured the confidentiality of the information they provided.

Last, rice millers were suspicious when it came to reporting the paddy they milled or sold because of tax issues. However, this problem was addressed by assuring millers that the survey was purely for academic purposes, the responses provided would remain strictly confidential and anonymous, and the government would not have access to the information as per the QUT ethics code.

Chapter 7: Results for rice farming and processing in Kenya

7.1 INTRODUCTION

This chapter provides the results for Kenyan rice farming and processing. Section 7.2 provides the technical, cost, allocative, scale efficiency and meta-frontier estimates of 773 rice farmers in Mwea, Ahero, West Kano and Bunyala schemes which thus addresses the first objective of the second part of the thesis by establishing the rice farming efficiencies and technology gap ratios across the schemes. Section 7.3 provides the results for 116 rice millers of Mwea who only mill the paddy for a fee and thus addresses the second objective of the second part of the thesis by establishing the rice processing and environmental efficiency of Mwea rice millers and the determinants of efficiency. Section 7.4 provides the Network DEA results for 26 rice millers who also double up as farmers, and thus addresses the last objective of the second part of the thesis by establishing the efficiency of the two stages of rice processing and its determinants.

7.2 RICE FARMING EFFICIENCIES

7.2.1 Technical, cost and allocative efficiency

Table 7.1 provides the efficiency scores results. The mean technical, allocative, cost and scale efficiency were 0.512, 0.581, 0.287 and 0.839 respectively, implying that there was a 48.8% greater potential to increase output further given the same input levels; a 41.9% greater potential given optimal input prices; a 71.3% increase possible through reducing costs and 16.1% potential increase given optimal scale. 96.8% of the farms were scale-inefficient, with 35.8% operating on increasing returns to scale, 60.9% operating under decreasing returns to scale and only 3.2% were scale efficient. The results therefore suggest that cost inefficiency is the primary cause of Kenya's rice farming inefficiency.

Table 7.1 Summary of technical, allocative and cost-efficiency

Range	Technical		Allocative		Cost		Scale	
	No of DMUs	**%**	**No of DMUs**	**%**	**No of DMUs**	**%**	**No of DMUs**	**%**
<0.1	0	0	0	0	10	1.29	0	0
0.1-0.199	12	1.55	4	0.52	177	22.90	1	0.13
0.2-0.299	79	10.22	35	4.53	336	43.47	4	0.52
0.3-0.399	182	23.54	86	11.13	137	17.72	8	1.03
0.4-0.499	181	23.42	129	16.69	54	6.99	19	2.46
0.5-0.599	102	13.2	183	23.67	27	3.49	40	5.17
0.6-0.699	75	9.7	136	17.59	15	1.94	88	11.38
0.7-0.799	42	5.43	110	14.23	7	0.91	76	9.83
0.8-0.899	29	3.75	60	7.76	4	0.52	142	18.37
0.9-0.999	24	3.1	26	3.36	2	0.26	370	47.87
1	47	6.08	4	0.52	4	0.52	25	3.23
IRS	277	35.83						
DRS	471	60.93						
CRS	25	3.23						
Mean	0.512		0.581		0.287		0.839	
Minimum	0.109		0.134		0.047		0.197	
Maximum	1.000		1.000		1.000		1.000	
Std. Dev	0.214		0.173		0.141		0.158	

Source: Results estimates

Note: IRS = increasing returns to scale; DRS = decreasing returns to scale.

7.2.2 Input use ratios

Table 7.2 provides the ratios of input use, which compare the cost-efficiency input minimising levels with the technical efficiency input levels. A ratio greater or less than one implies an overuse or underuse of the input, while a ratio of one indicates optimum input use.

Examining rice land use in Mwea indicated that 10.1% of the farmers underutilised land, 40% used land optimally, while 49.9% over-utilised land. In West Kano 0.79% of farmers' underutilised land, 2.4% used land optimally, and 96.9% over-utilised land. At Ahero scheme, 6.9% of rice farmers underutilised land while 93.1% over-utilised the land, with no farmers utilising land optimally. In Bunyala, 3.1% of rice farmers underused land and 96.9% over-utilised land, with no farmers using land optimally. The above finding has a significant policy implication, since it suggests that rice output can be increased further with optimal land use. In Kenya, land in the rice growing regions is purely rice monocropping based and therefore it is left fallow during the rice off-season. Clearly, there is scope for introducing policies which would induce farmers to utilise the land during the off-season. For example, an alternate non-rice cropping pattern of short season crops such as tomatoes, watermelons, beans or maize could be introduced which would also enhance soil fertility and better land utilisation.

Examining fertiliser use in Mwea revealed that 11.2% of the sample underutilised fertiliser, 6.4% used fertiliser optimally and 82.4% over-utilised fertilisers. In West Kano, 11.02% of the sample underutilised fertiliser, 1.57% used fertiliser optimally and 87.4% over-utilised fertilisers. In Ahero, 3.8% of the farmers' underutilised fertiliser, 4.6% used fertiliser optimally while 91.6% over-utilised fertiliser. In Bunyala 3.1% of the sample underutilised fertiliser, 9.4% used fertiliser optimally while 87.5% over-utilised fertiliser.

In the case of pesticide use by Mwea farmers, 19.5% of the sample underutilised pesticides, 4.76% used it optimally while 75.8% over-utilised pesticides. In West Kano, Ahero and Bunyala, none of the farmers utilised pesticides optimally. In West Kano, 17.3 % of the farmers underutilised pesticides while 82.7% over-utilised it. 12.2 % of Ahero rice farmers' underutilised pesticides while 87.8% over-utilising it. In Bunyala, 6.3 % of the sample underutilised pesticides while 93.8% over-utilising pesticides. Overusing fertiliser and pesticides has an important policy implication since excess fertiliser and pesticides use may adversely affect human health and lead to land degradation and therefore low rice productivity. Hence educating farmers on the optimal use of these two inputs will not only lower the cost of rice production, but also reduce the adverse effects of fertiliser and pesticide use. Also, reducing the government fertiliser subsidy would help reduce fertiliser overuse.

Examining seed use in Mwea revealed that 22.8% of the sample underutilised seed, 14.9% used seed optimally while 62.3% over-utilised seed. In West Kano, 4.7% of rice farmers' underutilised seed, 3.9% used it optimally while 91.3% over-utilised seed. In Ahero, 2.3% of the farmers underutilised seed, none used seed optimally while 97.7% over-utilised seed. 3.1% of Bunyala rice farmers underutilised seed, 15.6% utilised it optimally while 81.3% over-utilised seed. Thus, educating farmers on optimal seed use could help reduce wastage.

Examining labour use in Mwea revealed that 0.83% of the sample underutilised labour, 1.24% used it optimally while 97.9% over-utilised labour. In West Kano, Ahero and Bunyala, none of the farmers utilised labour optimally. In West Kano, 0.79% of the sample underutilised labour while 99.2% over-utilised labour. In Ahero, 1.5% of the sample underutilised labour while 98.5% over-utilised labour. In Bunyala, all the farmers' over-utilised labour. The reasons for labour overuse are three-fold. First, rice farming in most cases is highly labour-intensive, hence creating the risk of over-utilisation. Second, over-utilising labour in rice farming in Kenya may also be an indication of disguised unemployment. Although, farms are small, they utilise about 34 persons per rice season on average, as observed from the mean. However, the survey's use of the average labour wage for farmers who use family labour may have increased the rate of disguised employment. Thus, reducing family labour cost may reduce the allocative inefficiency on labour. Third, in the absence of other off-farm economic activities such as tourism and other industries, it becomes difficult to reallocate labour from rice farming to other activities.

Table 7.2 Input use ratios

Region	Variable	Under use		Optimal use		Overuse	
		No	%	No	%	No	%
Mwea	Land	49	10.14	193	39.96	241	49.9
	Fertiliser	54	11.18	31	6.42	398	82.4
	Pesticide	94	19.46	23	4.76	366	75.78
	Seed	110	22.77	72	14.91	301	62.32
	Labour	4	0.83	6	1.24	473	97.93
West Kano	Land	1	0.79	3	2.36	123	96.85
	Fertiliser	14	11.02	2	1.57	111	87.4
	Pesticide	22	17.32	0	0	105	82.68
	Seed	6	4.72	5	3.94	116	91.34
	Labour	1	0.79	0	0	126	99.21
Ahero	Land	9	6.87	0	0	122	93.13
	Fertiliser	5	3.82	6	4.58	120	91.60
	Pesticide	16	12.21	0	0	115	87.79
	Seed	3	2.29	0	0	128	97.71
	Labour	2	1.53	0	0	129	98.47
Bunyala	Land	1	3.13	0	0	31	96.88
	Fertiliser	1	3.13	3	9.38	28	87.5
	Pesticide	2	6.25	0	0	30	93.75
	Seed	1	3.13	5	15.63	26	81.25
	Labour	0	0	0	0	32	100

Source: Results estimates

7.2.3 Meta-technology ratio

7.2.3.1 Hypothesis testing for technical, cost and allocative efficiency

To find if the technical, scale, allocative and cost-efficiency means were statistically different across regions, a Kruskal Wallis Test was carried out. The following hypotheses were tested:

Hypothesis 1: H_0 = mean technical efficiency is the same in all the regions

H_1 = mean technical efficiency is different across the regions

Hypothesis 2: H_0 = mean scale efficiency is the same in all the regions

H_1 = mean scale efficiency is different across the regions

Hypothesis 3: H_0 = mean allocative efficiency is the same in all the regions

H_1 = mean allocative efficiency is different across the regions

Hypothesis 4: H_0 = mean cost-efficiency is the same in all the regions

H_1 = mean cost-efficiency is different across the regions

The results indicate that the distribution of the means were statistically different across the regions since the null hypothesis was rejected in all cases (see

Table 7.3). This implies that efficiencies varied across the regions which thus formed the basis for calculating the technology gap ratios between the regions as shown in Table 7.6.

Table 7.3 Hypothesis testing results for technical, scale, allocative and cost-efficiency

Variable	**P value**	**Result**
Technical efficiency	0.000	Rejected
Scale efficiency	0.000	Rejected
Allocative efficiency	0.000	Rejected
Cost-efficiency	0.000	Rejected

Source: Results estimates

7.2.3.2 Pooled and regional meta-frontiers of technical, allocative and cost-efficiency

Table 7.4 provides the meta-frontier estimates of the pooled data. The technical, allocative and cost-efficiency of Mwea were 0.556, 0.538 and 0.296 respectively, while those of West Kano were 0.475, 0.603 and 0.27, respectively. The technical, allocative and cost-efficiency of Ahero was 0.402, 0.68 and 0.266 respectively while that of Bunyala were 0.45, 0.721 and 0.310, respectively.

Analysing regional efficiencies as shown in Table 7.5 indicates that the technical, allocative and cost-efficiency of Mwea were 0.557, 0.538 and 0.296 respectively; West Kano's - 0.784, 0.641 and 0.501, Ahero's - 0.833, 0.568 and 0.457 while that of Bunyala was 0.937, 0.729 and 0.689 respectively. The results thus suggest that a narrow gap existed between the region and the meta-frontier results for Mwea, while a wider gap existed for West Kano, Ahero and Bunyala.

Table 7.6 provides the gaps in technical, allocative and cost-efficiency, which were 0.998, 1.000 and 1.000 for Mwea; 0.605, 0.941 and 0.367 for West Kano; 0.482, 1.197 and 0.582 for Ahero, and 0.480, 0.989 and 0.45 respectively for Bunyala.

The results thus suggest that Mwea rice farmers were more technical, allocative and cost efficient than rice farmers in the other schemes, while Ahero rice farmers allocated the inputs more efficiently. West Kano and Bunyala appeared worse off in all the efficiencies. Mwea may have an advantage over the other rice-growing regions due to its proximity to the capital city, Nairobi where key inputs such as fertiliser are easily accessible. The transportation cost of inputs e.g. fertiliser, seed and other inputs from Nairobi City made them more expensive in the other regions. As noted by Kherallah et al. (2002), fertiliser is much more expensive in Africa than elsewhere in the world due to high transportation costs, making it difficult for poor farmers to afford it. Mwea also benefits from its proximity to the Mwea Rice Research Centre and nearby higher institutions of learning conducting rice research in the area.

Ahero's advantage of allocating inputs better probably may be due to its proximity to Kisumu City, hence allowing farmers to efficiently allocate labour between rice farming and other economic activities such as fishing, retail business and livestock keeping. Ahero also has large SRI experiment sites set up by researchers which encourage farmers to adopt such technology – all of which would impact on the reallocation of inputs. In this way, bridging the gap between the prices and choices of inputs would help West Kano, Ahero and Bunyala reduce the inefficiencies.

Table 7.4 Meta-frontier regional efficiencies estimates from pooled data

	Mwea Irrigation Scheme						West Kano Irrigation scheme					
	Technical		Allocative		Cost		Technical		Allocative		Cost	
Range	No of DMUs	%	No of DMUs	%	No of DMUs	%	No of DMUs	%	No of DMUs	%	No of DMUs	%
<0.1	0	0	0	0	8	1.66	0	0	0	0	0	0
0.1-0.199	1	0.21	2	0.41	113	23.4	3	2.36	0	0	28	22.05
0.2-0.299	26	5.38	31	6.42	199	41.2	19	14.96	2	1.57	63	49.61
0.3-0.399	101	20.91	68	14.08	81	16.77	32	25.20	9	7.09	25	19.69
0.4-0.499	117	24.22	100	20.70	37	7.66	30	23.62	20	15.75	7	5.51
0.5-0.599	66	13.66	120	24.84	18	3.73	18	14.17	41	32.28	2	1.57
0.6-0.699	59	12.22	85	17.60	12	2.48	7	5.51	21	16.54	1	0.79
0.7-0.799	31	6.42	46	9.52	6	1.24	6	4.72	21	16.54	1	0.79
0.8-0.899	23	4.76	21	4.35	3	0.62	2	1.57	10	7.87	0	0
0.9-0.999	19	3.93	6	1.24	2	0.41	5	3.94	3	2.36	0	0
1	40	8.28	4	0.83	4	0.83	5	3.94	0	0	0	0
Average	0.556		0.538		0.296		0.475		0.603		0.270	
Minimum	0.157		0.134		0.082		0.147		0.261		0.106	
Maximum	1.000		1.000		1.000		1.000		0.942		0.704	
Std. Dev	0.216		0.163		0.156		0.206		0.146		0.099	

Source: Results estimates

Table 7.4 continued

	Ahero Irrigation Scheme						**Bunyala Irrigation scheme**					
	Technical		**Allocative**		**Cost**		**Technical**		**Allocative**		**Cost**	
Range	**No of DMUs**	**%**	**No of DMUs**	**%**	**No of DMUs**	**%**	**No of DMUs**	**%**	**No of DMUs**	**%**	**No of DMUs**	**%**
<0.1	0	0	0	0	2	1.53	0	0	0	0	0	0
0.1-0.199	7	5.34	2	1.53	30	22.90	1	3.13	0	0	6	18.75
0.2-0.299	30	22.90	2	1.53	65	49.62	4	12.50	0	0	9	28.13
0.3-0.399	39	29.77	9	6.87	17	12.98	10	31.25	0	0	14	43.75
0.4-0.499	29	22.14	7	5.34	9	6.87	5	15.63	2	1.53	1	3.125
0.5-0.599	11	8.40	17	12.98	6	4.58	7	21.88	5	3.82	1	3.125
0.6-0.699	6	4.58	21	16.03	1	0.76	3	9.38	9	6.87	1	3.125
0.7-0.799	5	3.82	38	29.01	0	0	0	0	5	3.82	0	0
0.8-0.899	3	2.29	24	18.32	1	0.76	1	3.13	5	3.82	0	0
0.9-0.999	0	0	11	8.40	0	0	0	0	6	4.58	0	0
1	1	0.76	0	0	0	0	1	3.13	0	0	0	0
Average	0.402		0.680		0.266		0.450		0.721		0.310	
Minimum	0.109		0.15		0.047		0.167		0.424		0.158	
Maximum	1.000		0.974		0.875		1.000		0.985		0.605	
Std. Dev	0.164		0.177		0.122		0.179		0.156		0.103	

Source: Results estimates

Table 7.5 Regional meta-frontier efficiencies estimate (when each region is analysed separately)

	Mwea Irrigation Scheme						West Kano Irrigation scheme					
	Technical		**Allocative**		**Cost**		**Technical**		**Allocative**		**Cost**	
Range	**No of DMUs**	**%**	**No of DMUs**	**%**	**No of DMUs**	**%**	**No of DMUs**	**%**	**No of DMUs**	**%**	**No of DMUs**	**%**
<0.1	0	0	0	0	8	1.66	0	0	0	0	0	0
0.1-0.199	1	0.21	2	0.41	113	23.40	0	0	0	0	0	0
0.2-0.299	25	5.18	32	6.63	199	41.20	0	0	0	0	10	7.87
0.3-0.399	100	20.7	68	14.08	81	16.77	2	1.57	6	4.72	28	22.05
0.4-0.499	118	24.43	99	20.50	37	7.66	7	5.51	9	7.09	30	23.62
0.5-0.599	65	13.46	120	24.84	18	3.73	10	7.87	35	27.56	30	23.62
0.6-0.699	60	12.42	86	17.81	12	2.48	24	18.90	40	31.5	15	11.81
0.7-0.799	32	6.63	45	9.32	6	1.24	26	20.47	22	17.32	6	4.72
0.8-0.899	22	4.55	22	4.55	3	0.62	14	11.02	10	7.87	5	3.94
0.9-0.999	19	3.93	5	1.04	2	0.41	7	5.51	3	2.36	1	0.79
1	41	8.49	4	0.83	4	0.83	37	29.13	2	1.57	2	1.57
Average	0.557		0.538		0.296		0.784		0.641		0.501	
Minimum	0.157		0.134		0.082		0.350		0.341		0.220	
Maximum	1.000		1.000		1.000		1.000		1.000		1.000	
Std. Dev	0.216		0.162		0.156		0.183		0.131		0.161	

Source: Results estimates

Table 7.5 continued

	Ahero Irrigation Scheme						Bunyala Irrigation scheme					
	Technical		Allocative		Cost		Technical		Allocative		Cost	
Range	No of DMUs	%	No of DMUs	%	No of DMUs	%	No of DMUs	%	No of DMUs	%	No of DMUs	%
<0.1	0	0	1	0.76	2	1.53	0	0	0	0	0	0
0.1-0.199	0	0	11	8.40	15	11.45	0	0	0	0	0	0
0.2-0.299	4	3.05	15	11.45	21	16.03	0	0	0	0	1	3.13
0.3-0.399	2	1.53	14	10.69	25	19.08	0	0	1	3.13	3	9.38
0.4-0.499	4	3.05	12	9.16	23	17.56	2	6.25	3	9.38	3	9.38
0.5-0.599	17	12.98	14	10.69	11	8.40	0	0	3	9.38	2	6.25
0.6-0.699	8	6.11	20	15.27	12	9.16	0	0	7	21.88	8	25
0.7-0.799	7	5.34	12	9.16	7	5.34	2	6.25	8	25	5	15.63
0.8-0.899	12	9.16	15	11.45	4	3.05	3	9.38	3	9.38	3	9.38
0.9-0.999	24	18.32	11	8.40	5	3.82	0	0	2	6.25	2	6.25
1	53	40.46	6	4.58	6	4.58	25	78.13	5	15.63	5	15.63
	0.833		0.568		0.457		0.937		0.729		0.689	
	0.250		0.050		0.048		0.456		0.350		0.285	
	1.000		1.000		1.000		1.000		1.000		1.000	
	0.215		0.259		0.239		0.143		0.178		0.215	

Source: Results estimates

Table 7.6 Summary of the means and the gap ratios

		Mwea			West Kano			Ahero			Bunyala		
		TE	**AE**	**CE**	**TE**	**AE**	**CE**	**TE**	**AE**	**CE**	**TE**	**AE**	**CE**
Pooled frontier	Average	0.556	0.538	0.296	0.475	0.603	0.270	0.402	0.680	0.266	0.450	0.721	0.310
	Minimum	0.157	0.134	0.082	0.147	0.261	0.106	0.109	0.150	0.047	0.167	0.424	0.158
	Maximum	1.000	1.000	1.000	1.000	0.942	0.704	1.000	0.974	0.875	1.000	0.985	0.605
	Standard Deviation	0.216	0.163	0.156	0.206	0.146	0.099	0.164	0.177	0.122	0.179	0.156	0.103
Region frontier	Average	0.557	0.538	0.296	0.784	0.641	0.501	0.833	0.568	0.457	0.937	0.729	0.689
	Minimum	0.157	0.134	0.082	0.350	0.341	0.220	0.250	0.050	0.048	0.456	0.350	0.285
	Maximum	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	Standard Deviation	0.216	0.162	0.156	0.183	0.131	0.161	0.215	0.259	0.239	0.141	0.178	0.215
	Gap Ratio	**0.998**	**1.000**	**1.000**	**0.605**	**0.941**	**0.367**	**0.482**	**1.197**	**0.582**	**0.480**	**0.989**	**0.450**

Source: Results estimates

Note: TE= technical efficiency; AE = allocative efficiency and CE = cost-efficiency

7.2.4 Determinants of efficiency

7.2.4.1 Determinants of technical efficiency

Table 7.7 provides the FRM estimates for technical efficiency. In the one-part models (linear models) age, farmer’s gender and adopting technologies were significant at the 10% and 5% levels, thereby explaining why some farmers were efficient. However, experience, extension, market distance, years of schooling, humidity, rainfall and temperature did not explain the inefficiency, since the variables were not statistically significant. At 10% and 5% significance levels for the logit and cloglog model, age, farmer’s gender, humidity, rainfall, temperature and adopting technologies explained the inefficiency.

An examination of the second part of the two-part models, showed that adopting technologies was the reason why some farmers were more efficient (5% significance level for the cloglog and at 10% significance level for the logit model). In examining why some farmers were inefficient, their age, gender and level of humidity reduced their efficiency scores at 5% and 1% significance level for all the models. Adopting technologies and temperature reduced their inefficiency at the 5% and 10% significance level for all the models.

The role of gender in rice farming remains important. The results indicate that a rice farmer's gender had a negative relationship with efficiency, implying that males were more inefficient in rice farming than the females. The finding contradicts the bulk of the existing literature which finds males more efficient than females (Ironkwe et al., 2014; Oladeebo, 2012). However, it may be assumed that given women play a critical role in rice farming by providing close to half of the total labour input in rice farming, then this finding holds.

The age of the farmer was found to be negatively correlated with efficiency. The finding corroborates the works of Mugera and Featherstone (2008) who found that age increased inefficiency among a sample of 126 people rearing hog in the Philippines. The results also confirmed that young farmers tend to adopt newer technologies faster than the older farmers hence, the higher efficiency.

The role of climatic factors in rice farming remains important. The average humidity and rainfall, affected efficiency negatively, while temperature positively affected efficiency. Sarker et al. (2012) and HoAfricain et al. (2013) also found rainfall to be negatively associated with AUS variety rice farming in Bangladesh. However, in relation to humidity and temperature, this study results contradict the findings of these authors. However, Banaszek and Siebenmorgen (1990) found that lower relative humidity reduced head rice yield less while Mahmood et al. (2012) found that in India's Punjab province an increase in temperature by 1.5^{0}C and 3^{0}C increased rice yield by 2.09% and 4.33%, respectively. Rice requires optimum rainfall, temperature and humidity for its vegetative growth and to produce paddy therefore policies that spearhead adaptive strategies to mitigate adverse effects of the climatic factors would benefit rice farmers.

Adopting technologies has been found the key to increasing rice output particularly in Asia. In this study, those farmers who adopted improved seed and water saving technologies were more efficient than the conventional farmers. Thus, investing in improved rice technologies will clearly help increase rice output in Kenya.

7.2.4.2 Determinants of allocative and cost-efficiency

The FRM estimates for allocative efficiency and cost-efficiency are provided in Table 7.8 and 7.9, respectively.

In the one-part models age, experience, rice farmer gender, the region of the farmer and adopting technologies all had an impact on allocative efficiency at the 10%, 5% and 1% significance levels. The negative relationship between age and allocative efficiency implies that younger rice farmers were more responsive to allocation of inputs based on their prices than older farmers. The negative relationship between adopting technologies and efficiency scores suggests that farmers adopting new technologies failed to allocate inputs optimally based on their prices. The scenario is common with SRI, which requires more labour than the traditional method of rice growing. Adopting SRI requires reallocating inputs to match the needs of the new technology which, if not implemented, leads to further inefficiency. The negative relationship between gender and allocative efficiency implies that females are better at allocating inputs based on their prices than males. The dummy for the region had a negative relationship with allocative efficiency, indicating that Mwea farmers were less effective in allocating inputs based on their prices than rice farmers in the other areas. Mwea is purely a rice farming area with fewer or no other economic activities such as fishing, livestock keeping and tourism, which are more common in the other regions. Consequently, the possibility of Mwea rice farmers failing to reallocate labour well heightens. However, experience was found to be positively associated with allocative efficiency implying that more experienced farmers achieved allocative efficiency than the less experienced farmers.

Examining cost-efficiency in the one-part and two-part models, age, gender and experience were found to significantly affect cost-efficiency at the 5% and 1% significance levels. The negative relationship between age and cost-efficiency implies that younger rice farmers were more sensitive to the cost of inputs based on their prices than older farmers. The finding contradicts results of similar studies. For example, Ogundari (2010) found older operators had a higher-cost-efficiency than younger operators among saw millers in Nigeria, while Kilic et al. (2009) found older farmers had a higher-cost-efficiency than younger farmers among hazelnut producers in Turkey. The negative impact of gender on cost-efficiency implies that female rice farmers were more responsive to the cost of inputs based on their prices than the male farmers. The positive relationship between years of experience and cost-efficiency implies that more experienced rice farmers were more responsive to the cost of inputs based on their prices than the less experienced farmers.

Table 7.7 Determinants of technical efficiency

One-part models					Two-part models						
					1st Part		2nd Part				
Variable	**Linear**	**Tobit**	**logit**	**cloglog**	**logit**	**cloglog**	**Linear**	**logit**	**probit**	**loglog**	**cloglog**
Intercept	2.140*** (0.345)	2.211*** (0.364)	6.677 *** (1.153)	4.450*** (0.846)	21.97 (1037)	21.44 (991.2)	1.761*** (0.297)	5.144*** (1.012)	3.210*** (0.632)	3.935*** (0.699)	3.469*** (0.759)
Age (years)	-0.002* (0.001)	-0.002* (0.001)	-0.006* (0.003)	-0.005** (0.002)	-0.010 (0.018)	-0.010 (0.017)	-0.002** (0.001)	-0.006** (0.003)	-0.004** (0.002)	-0.004** (0.002)	-0.005** (0.002)
Experience (years)	0.000 (0.001)	0.000 (0.001)	0.001 (0.003)	0.000 (0.002)	0.003 (0.017)	0.003 (0.016)	0.000 (0.001)	0.001 (0.003)	0.000 (0.002)	0.000 (0.002)	0.000 (0.002)
Extension (km)	-0.001 (0.002)	-0.001 (0.002)	-0.003 (0.009)	-0.002 (0.006)	-0.012 (0.046)	-0.011 (0.044)	-0.000 (0.002)	-0.002 (0.007)	-0.001 (0.005)	-0.001 (0.005)	-0.001 (0.005)
Gender (0 = female; 1=male)	-0.039** (0.017)	-0.041** (0.018)	-0.160** (0.071)	-0.112** (0.049)	-0.232 (0.332)	-0.224 (0.317)	-0.034** (0.015)	-0.138** (0.062)	-0.087** (0.039)	-0.098** (0.044)	-0.101** (0.044)
Humidity (%)	-0.024 (0.048)	-0.024 (0.050)	-0.114*** (0.035)	-0.097*** (0.025)	-2.355 (333.7)	-2.335 (319.0)	-0.023 (0.040)	-0.111*** (0.029)	-0.067*** (0.018)	-0.063*** (0.020)	-0.094*** (0.022)
Market (km)	-0.001 (0.003)	-0.001 (0.003)	-0.002 (0.012)	-0.001 (0.008)	0.000 (0.053)	0.001 (0.051)	-0.000 (0.002)	-0.002 (0.009)	-0.001 (0.006)	-0.002 (0.007)	-0.001 (0.007)
Rainfall (mm)	-0.000 (0.000)	-0.000 (0.001)	-0.001*** (0.000)	-0.001*** (0.000)	-0.024 (3.366)	-0.024 (3.218)	-0.000 (0.000)	-0.001*** (0.000)	-0.001*** (0.000)	-0.001*** (0.000)	-0.001*** (0.000)
School (years)	-0.001 (0.002)	-0.001 (0.002)	-0.005 (0.009)	-0.004 (0.007)	0.011 (0.048)	0.011 (0.046)	-0.002 (0.002)	-0.007 (0.008)	-0.004 (0.005)	-0.005 (0.006)	-0.005 (0.006)
Technologies (1=adopted; 0= not adopted)	0.048** (0.018)	0.052** (0.019)	0.197** (0.079)	0.146*** (0.056)	0.735* (0.347)	0.705** (0.328)	0.030* (0.016)	0.121* (0.068)	0.075* (0.042)	0.082* (0.048)	0.091* (0.050)
Temperature (^{0}C)	0.022 (0.166)	0.018 (0.174)	0.142 (0.117)	0.155* (0.085)	7.442 (1162)	7.392 (1111)	0.034 (0.140)	0.192* (0.101)	0.112* (0.063)	0.085 (0.070)	0.185** (0.075)
Sigma		0.215*** (0.006)									
Number of observations	773	773	773	773	773	773	726	726	726	726	726
R-squared	0.093	1.967	0.093	0.094	0.024	0.025	0.082	0.082	0.082	0.082	0.083

Source: Results estimate

Table 7.8 Determinants of allocative efficiency

One-part models					Two-part models						
					1st Part		**2nd Part**				
Variable	**Linear**	**Tobit**	**logit**	**cloglog**	**logit**	**cloglog**	**Linear**	**logit**	**probit**	**loglog**	**cloglog**
Intercept	0.707*** (0.035)	0.708*** (0.035)	0.860*** (0.153)	0.197* (0.102)	-17.69 (4388)	-17.62 (4210)	0.697*** (0.035)	0.820*** (0.149)	0.508*** (0.093)	1.006*** (0.114)	0.170* (0.100)
Age (years)	-0.002** (0.001)	-0.002** (0.001)	-0.006** (0.003)	-0.004** (0.002)	-0.117 (0.074)	-0.116 (0.072)	-0.001** (0.001)	-0.005** (0.003)	-0.003** (0.002)	-0.004** (0.002)	-0.004** (0.002)
Experience (years)	0.002** (0.001)	0.002** (0.001)	0.010*** (0.003)	0.007*** (0.002)	0.068 (0.059)	0.067 (0.058)	0.002** (0.001)	0.009*** (0.003)	0.006*** (0.002)	0.007*** (0.002)	0.006*** (0.002)
Extension (km)	-0.0000 (0.002)	0.000 (0.002)	0.000 (0.007)	0.000 (0.005)	0.074 (0.107)	0.074 (0.106)	-0.000 (0.002)	-0.002 (0.007)	-0.001 (0.005)	-0.001 (0.005)	-0.001 (0.005)
Gender (1=male; 0 = otherwise	-0.025* (0.013)	-0.025* (0.013)	-0.106* (0.057)	-0.063* (0.038)	0.112 (1.195)	0.083 (1.177)	-0.026* (0.013)	-0.108* (0.056)	-0.066* (0.035)	-0.088** (0.043)	-0.065* (0.038)
Market (km)	0.002 (0.002)	0.002 (0.002)	0.008 (0.009)	0.005 (0.006)	-0.265 (0.207)	-0.258 (0.204)	0.003 (0.002)	0.010 (0.009)	0.007 (0.006)	0.008 (0.007)	0.007 (0.006)
Region 1=Mwea; 0 = Otherwise	-0.130*** (0.015)	-0.130*** (0.015)	-0.544*** (0.062)	-0.357*** (0.041)	18.13 (4388)	18.02 (4210)	-0.136*** (0.014)	-0.565*** (0.062)	-0.351*** (0.038)	-0.439*** (0.048)	-0.372*** (0.040)
School (years)	0.001 (0.002)	0.001 (0.002)	0.003 (0.007)	0.002 (0.005)	-0.100 (0.159)	-0.098 (0.157)	0.001 (0.002)	0.005 (0.007)	0.003 (0.005)	0.003 (0.006)	0.003 (0.005)
Technologies (1= adopted; 0 = otherwise)	-0.050** (0.015)	-0.050** (0.015)	-0.208*** (0.065)	-0.134*** (0.044)	0.611 (1.210)	0.610 (1.192)	-0.051** (0.014)	-0.214*** (0.064)	-0.133*** (0.040)	-0.167*** (0.048)	-0.139*** (0.043)
Sigma		0.162*** (0.004)									
Number of observations	773	773	773	773	773	773	769	769	769	769	769
R-squared:		-0.22	0.134	0.133	0.015	0.016	0.145	0.146	0.146	0.146	0.145

Source: Results estimates

Table 7.9 Determinants of cost-efficiency

	One-part models				Two-part models						
					1st Part		2nd Part				
Variable	**Linear**	**Tobit**	**logit**	**cloglog**	**logit**	**cloglog**	**Linear**	**logit**	**probit**	**loglog**	**cloglog**
Intercept	0.381*** (0.030)	0.382** * (0.030)	-0.448*** (0.152)	-0.689*** (0.130)	-17.69 (4388)	-17.62 (4210)	0.367*** (0.028)	-0.513*** (0.139)	-0.325*** (0.083)	0.002 0.079	-0.746*** (0.118)
Age (years)	-0.002** (0.001)	-0.002** (0.001)	-0.011*** (0.003)	-0.009*** (0.003)	-0.117 (0.074)	-0.116 (0.072)	-0.002** (0.001)	-0.009*** (0.003)	-0.006*** (0.002)	-0.005*** (0.002)	-0.008*** (0.002)
Experience (years)	0.002** (0.001)	0.002** (0.001)	0.008*** (0.003)	0.007*** (0.002)	0.068 (0.059)	0.067 (0.058)	0.001** (0.001)	0.007*** (0.003)	0.004*** (0.002)	0.004** (0.002)	0.006*** (0.002)
Extension (Kms)	0.000 (0.002)	0.000 (0.002)	0.001 (0.007)	0.001 (0.006)	0.074 (0.107)	0.074 (0.106)	-0.000 (0.001)	-0.001 (0.007)	-0.001 (0.004)	0.000 (0.004)	-0.001 (0.006)
Gender (1=male; 0 = otherwise	-0.038** (0.011)	-0.038** (0.011)	-0.181*** (0.057)	-0.154*** (0.048)	0.112 (1.195)	0.083 (1.177)	-0.039** (0.011)	-0.189*** (0.055)	-0.113*** (0.033)	-0.108*** (0.032)	-0.160*** (0.046)
Market (Kms)	0.000 (0.002)	0.000 (0.002)	0.000 (0.009)	0.000 (0.008)	-0.265 (0.207)	-0.258 (0.204)	0.001 (0.002)	0.005 (0.008)	0.003 (0.005)	0.003 (0.005)	0.005 (0.007)
Region (1=Mwea; 0 = Otherwise	0.016 (0.013)	0.016 (0.013)	0.078 (0.054)	0.068 (0.046)	18.13 (4388)	18.02 (4210)	0.008 (0.012)	0.039 (0.051)	0.023 (0.031)	0.021 (0.029)	0.035 (0.044)
School (years)	-0.000 (0.002)	-0.000 (0.002)	-0.002 (0.007)	-0.002 (0.006)	-0.100 (0.159)	-0.098 (0.157)	0.000 (0.001)	0.000 (0.007)	0.000 (0.004)	0.000 (0.004)	0.000 (0.006)
Technologies (1= adopted; 0 = otherwise)	-0.001 (0.012)	-0.001 (0.012)	-0.006 (0.063)	-0.003 (0.054)	0.611 (1.210)	0.610 (1.192)	-0.003 (0.012)	-0.014 (0.059)	-0.009 (0.035)	-0.009 (0.033)	-0.012 (0.050)
Number of observations	773	773	773	773	773	773	769	769	769	769	769
R-squared:	0.030	-0.039	0.041	0.042	0.015	0.016	0.039	0.04	0.04	0.039	0.04

Source: Results estimates

7.2.5 Conclusion and recommendations

The technical efficiency of a sample of 773 rice farmers from four rice-growing schemes in Kenya were measured using DEA and the efficiency determinants were quantified using FRM. The results indicate a significant variation of the efficiency scores among the four regions.

The average technical, cost and allocative efficiency was 0.512, 0.287 and 0.581 respectively, which implies that on average output would be increased by 48.8% given the same level of inputs, by 41.9% given the optimal prices of the inputs and by reducing costs by 71.3%. Thus, the results suggest that cost remains the primary cause of inefficiency in Kenyan rice farming. Analysing each region's efficiency separately revealed that Mwea efficiency results were close to the meta-frontier results of the pooled data thus indicating a very narrow gap between the two estimates. The West Kano, Ahero and Bunyala efficiency scores were higher than that of the meta-frontier thus indicating a gap between the regional and meta-frontier results. Thus, Mwea appeared to be closer to the frontier, while Bunyala was very far from the frontier. The factors found to be associated with technical efficiency included: gender, age, humidity, rainfall, temperature and adopting technologies. Concerning cost and allocative efficiency, age, gender and experience were found to affect cost-efficiency and age, gender, region and adopting technologies had an impact on allocative efficiency.

Based on these findings, some important policy implications can be drawn. Policy interventions should aim at improving overall technical, cost and allocative efficiency of rice farming in Kenya. Thus, policy-makers should focus on enhancing rice farmers' technology adoption and training to bridge the inefficiency gap. Putting in place a planting schedule programme that will allow rice farmers utilise the land during the fallow months for short duration crops such as tomatoes, watermelons and beans would be one important means of helping farmers to enhance their livelihoods. Policies that target the challenges young farmers and either gender face in the rice farming systems will also contribute to narrowing the efficiency gap between the older and younger farmers, and between the male and female rice farmers. Policies that would narrow the technological gap between Mwea and the Western schemes would also be beneficial to the farmers. Spearheading adaptive strategies to mitigate adverse effects of climatic factors especially temperature, rainfall and humidity would be equally beneficial for farmers. In addition, very inefficient rice farmers should be encouraged to exit the industry to enable Policy-makers to reallocate the resources (especially land and water) to other more economic activities.

7.3 RICE PROCESSING EFFICIENCIES FOR MILLERS ONLY

7.3.1 Efficiency estimates and distribution

Table 7.10 provides the technical, allocative and cost-efficiency estimates of the surveyed mills which were 0.832, 0.444 and 0.346 respectively. The results imply that there was the possibility of maintaining the output levels by reducing inputs by 16.8%, decreasing costs by 55.6% and reducing the allocative inefficiency by 65.6%. Thus, the results reveal that cost and allocative inefficiency was the major cause of inefficiency in the rice milling sector.

The scale efficiency of 76.4% implies that output can be increased further by 23.6% by producing at optimal scale size. Most the mills (83.6%) operated under IRS thus suggesting that when the mills expanded their input levels, the output expanded at a much higher rate than the input levels. Respectively, eleven mills (9.5%) and eight mills (6.9%) operated at the most and least productive scale implying that expanding inputs by a certain percentage led to no or lower output expansion.

The average technical efficiency when incorporating carbon dioxide emissions from energy use was 75.6%, suggesting a further potential improvement of efficiency by 24.4% is possible by minimising carbon dioxide emissions. The efficiency ranged between 64.9% and 100%. The full technical efficiency mills also had full environmental efficiency when incorporating carbon dioxide emissions from energy use. Thus, it is shown that improving technical efficiency will help reduce environmental inefficiency.

The low cost and allocative efficiencies thus raise a fundamental question of whether the inefficient millers will still survive in a price taking, profit maximising framework. It would appear not for long since the long run profits will eventually equal zero in a competitive equilibrium context. However, in the short run, even in a competitive environment, inefficient millers can still survive with some losses provided it remains less than their fixed inputs cost (Kumbhakar & Lovell, 2003). The Mwea rice millers seem to have survived even under high cost and allocative inefficiencies as evidenced by the average number of such mills which still operate under such conditions. The reason for the mills' survival may be because although the rice market appears competitive, barriers to entry may still exist. For example, rice milling in Kenya is localised around the rice growing regions which are dominated by one ethnic group or culture, hence entrepreneurs from other areas may sometimes find it difficult to penetrate to such a market environment. Again, in Mwea, the practice of farmers storing their paddy at no cost in the rice mills for future milling or sale is common which means farmers mill or sell their paddy from that mill. Such arrangements indicate a deep-rooted relationship between the farmers and millers, an advantage a new entrant may not enjoy. Furthermore, farmers may prefer milling their paddy from millers they know than from new entrepreneurs that they don't know well.

A further reason why inefficient millers may remain in the market is that the Government policy aims at a balance between providing affordable rice to the consumers and maintaining a high farm gate price for paddy, which leaves the processing sector exposed to market forces. This uncertainty provides a small incentive to private entrepreneurs or big businesses to invest in the rice milling business or in more efficient processing technologies, thus leaves the existing millers to continue operating.

Table 7.10 Summary of efficiency estimates and frequency distribution

	TE		AE		CE		SE		EE	
Range	No of mills	% of mills	No of mills	% of mills	No of mills	% of mills	No. of mills	% of mills	No of mills	% of mills
<0.1	0	0	0	0	0	0	0	0	0	0
0.11-0.199	0	0	19	16.4	29	25.0	1	0.86	0	0
0.20-0.299	0	0	22	19	32	27.6	1	0.86	0	0
0.30-0.399	9	7.76	17	14.7	18	15.5	1	0.86	0	0
0.40-0.499	2	1.72	23	19.8	21	18.1	3	2.59	0	0
0.50-0.599	18	15.5	6	5.17	7	6.03	11	9.48	0	0
0.60-0.699	8	6.90	8	6.90	2	1.72	25	21.6	40	34.5
0.70-0.799	3	2.59	6	5.17	0	0	16	13.8	49	42.2
0.80-0.899	0	0	5	4.31	1	0.86	30	25.7	11	9.48
0.90-0.999	1	0.86	6	5.17	2	1.72	21	18.1	6	5.17
1.000	75	64.7	4	3.45	4	3.45	7	6.03	10	8.62
Average	0.832		0.444		0.346		0.764		0.756	
Minimum	0.333		0.102		0.102		0.110		0.649	
Maximum	1.000		1.000		1.000		1.000		1.000	
Std. Dev	0.241		0.247		0.205		0.178		0.100	

Source: Source: Results estimates

Note: TE = technical efficiency; AE = allocative efficiency; CE = cost-efficiency; SE = scale efficiency and EE = environmental efficiency

7.3.2 Input use ratios

Table 7.11 provides the input use ratios, which compare the cost-efficiency input minimising levels with the technical efficiency input levels. A ratio greater than one implies input overuse, and vice versa. Labour seemed over-utilised in 37.1% of the mills, 23.3% utilised labour optimally while 39.7% had a shortfall. The reasons for over-utilising labour may be due to the mills engaging more labour than required despite their small sizes and second, due to using the average labour wage in the analysis for those mills that used only family labour.

Examining energy, 93.1% of the mills over-utilised energy with 3.5% using energy optimally and with a shortfall in 3.5% of the mills. 92.2% of the mills over utilised machine hours, 4.3% of the mills had optimal utilisation with a shortfall machine hours in 3.5%.

Thus, it is evident that mills capacity was not being utilised efficiently due to over-utilising labour, energy and machine hours. Clearly, millers would improve their efficiency by reducing these input expenditures by the same percentage. Reducing family labour cost may also reduce the cost and allocative inefficiency.

Table 7.11 Input use ratios

	Labour	Energy	Machine hours
Optimum use mills (%)	23.28	3.45	4.31
Over utilising mills (%)	37.07	93.10	92.24
Shortfall (%)	39.66	3.45	3.45

Source: Results estimates

7.3.3 Determinants of efficiency

The technical, allocative and cost-efficiency determinants are provided in Tables 7.12, 7.13 and 7.14 respectively.

In the one-part models, the number of times the mill was serviced, energy type and number of household members explained the technical inefficiency, while miller's age, years of experience and age of the mill (number of years of used) were not significant. For cost-efficiency at 5 and 10% level of significance age, energy type, number of household members, education level (schooling years) and age of the mill significantly affected cost-efficiency, while years of experience did not affect efficiency. For allocative efficiency- at 5 and 10% level of significance, age, energy type, number of years of schooling and age of the mill significantly affected cost-efficiency while years of experience and number of household members did not affect efficiency.

The unexpected result of a negative impact of education on efficiency contradicts the bulk of existing literature but reinforces the findings by Fleming and Lummani (2001), who found that education had a negative impact on efficiency in Papua New Guinea. In the milling business, the more educated millers in most cases preferred formal employment and left the management of their mills under a paid operator who in most cases may not have been keen on using resources well, hence the inefficiency. Considering that the technology the millers are using is not modern (old mills), it is possible that the effect of education on milling may not be effective under such unmodernised technology. Patrick and Kehrberg (1973) found schooling returns to be negative or low in agricultural areas of Eastern Brazil, but gradually increased with the level of modernisation. However, the results for number of years of schooling were not significant for the technical efficiency models which implies that the level of education did not significantly affect technical efficiency.

At 10% level of significance, a negative relationship was shown to exist between energy type and technical efficiency scores in all the two-part model but were not significant for the one-part models except for the cloglog model. Kenya has a low electrification rate (as is the case for the rest of Africa) with only 18% of the Kenyan households and 4% of the rural households having access to grid electricity (Wolde-Rufael, 2005; Kiplagat et al., 2011). Frequent rolling blackouts further characterise the grid power energy sector, thus explaining the negative impact on technical efficiency. The allocative and cost-efficiency estimates indicate that at a 1% significance level, a positive relationship exists between energy type and allocative and cost-efficiency scores in all the one-part models. However, for the first part of the two-part model, the results were not significant. The second part of the two-part model results reveal that energy type has a positive relationship with cost and allocative efficiency, implying that inefficient millers become better off when using electricity for milling than when using fuel. A positive association between energy type and allocative efficiency maybe because electricity bills are due at the end of each month hence giving millers ample time to plan for the milling expenses than those who purchase fuel for milling on a day to day basis.

A positive association was found between the number of times the mill is serviced and technical efficiency scores in all the models which imply that regular servicing improved technical efficiency. The estimates for allocative and cost-efficiency indicate that at 10% significance level, a negative association exists between the number of times the mill is serviced and cost-efficiency in linear and logit models in the one-part models but the variable was not significant for allocative efficiency. In the two-part model the results were all significant for all the second part of the two-part models except for the linear model for cost-efficiency estimates. Servicing in most cases involves changing of spare parts, oiling and greasing, which may improve technical efficiency of millers. However, a negative association between allocative efficiency scores and the number of times the mill was serviced implies that the millers fail to reallocate inputs well when halting the milling process for servicing purpose. The increased number of servicing also implies higher costs, hence the negative association between number of times the mill was serviced and cost-efficiency.

Furthermore, most of the mills are imported which implied that some spare parts may not be available in the local market imposing an extra cost in importing the spares.

Age had a positive association with cost and allocative efficiency in the one-part models and part one of the two-part models, which indicates that older millers were better at achieving cost and allocative efficiency than younger millers. This corroborates the findings of Ogundari (2010) who found older operators had a higher-cost-efficiency than younger operators among saw millers in Nigeria while Kilic et al. (2009) found older farmers had a higher-cost-efficiency than younger farmers among hazelnut producers in Turkey. Considering that this is business older millers may be more conscious in maximising profits than the younger millers. Furthermore, the older millers may have more established effective business networks which make them better at allocating inputs based on their prices or using inputs optimally based on their prices.

The number of householders had a negative association with technical, cost and allocative efficiency, which indicates that inefficiency increased with the number of household members. A larger household means that there is increased number of dependants than those with a smaller size. Parikha and Shah (1994) also found a positive relationship between the number of household members and farmers' technical inefficiency in North West Frontier Province of Pakistan.

The age of the mill coefficient had a negative relationship with cost-efficiency at 10% significance level in the one-part models which implies mill performance declines with age. Gunatilake and Gopalakrishnan (2010) also found a negative relationship between saw milling machinery age and efficiency scores among sawmills in Sri Lanka which reinforces the above finding.

Table 7.12 Technical efficiency estimates for linear, tobit, logit and selected fractional regression models

	One-part models				**Two-part models**						
					1st Part		**2nd Part**				
	Linear	**Tobit**	**logit**	**cloglog**	**logit**	**cloglog**	**Linear**	**logit**	**probit**	**loglog**	**cloglog**
Constant	0.936*** (0.126)	1.535*** (0.368)	2.479***(0.872)	1.058*** (0.394)	1.784 (1.211)	0.921 (0.715)	0.423*** (0.146)	-0.317 (0.492)	-0.197 (0.307)	0.128 (0.352)	-0.580 (0.355)
Age	0.003 (0.003)	0.011 (0.008)	0.028 (0.024)	0.012 (0.010)	0.043 (0.031)	0.022 (0.018)	-0.001 (0.003)	-0.003 (0.007)	-0.002 (0.005)	-0.003 (0.005)	-0.002 (0.005)
Experience	0.000 (0.007)	0.001 (0.018)	-0.005 (0.045)	0.001 (0.020)	0.006 (0.061)	0.004 (0.036)	-0.001 (0.007)	-0.004 (0.025)	-0.003 (0.016)	-0.002 (0.018)	-0.004 (0.018)
Energy type	-0.047 (0.047)	-0.168 (0.125)	-0.363 (0.323)	-0.163* (0.152)	-0.728* (0.431)	-0.444* (0.269)	0.069* (0.042)	0.281* (0.149)	0.175* (0.093)	0.210* (0.109)	0.192* (0.104)
Household members	-0.027* (0.016)	-0.099** (0.049)	-0.237* (0.138)	-0.112 (0.058)	-0.375** (0.179)	-0.222** (0.100)	0.017 (0.018)	0.070 (0.068)	0.043 (0.043)	0.054 (0.049)	0.046 (0.049)
School years	-0.012 (0.009)	-0.033 (0.025)	-0.097 (0.064)	-0.045 (0.031)	-0.010 (0.086)	-0.060 (0.052)	-0.004 (0.009)	-0.018 (0.033)	-0.011 (0.021)	-0.013 (0.024)	-0.013 (0.023)
Servicing	0.003** (0.001)	0.008** (0.004)	0.025** (0.010)	0.012*** (0.004)	0.023* (0.013)	0.014* (0.008)	0.003* (0.002)	0.012*** (0.005)	0.007*** (0.003)	0.009*** (0.003)	0.008** (0.003)
Years of mill use	-0.004 (0.007)	-0.017 (0.019)	-0.031 (0.049)	-0.021 (0.023)	-0.058 (0.064)	-0.047 (0.040)	0.005 (0.008)	0.020 (0.027)	0.012 (0.017)	0.014 (0.020)	0.014 (0.019)
Sigma		0.533*** (0.070)									
Number of observations	116	116	116	116	116	116	41	41	41	41	41
R-squared	0.083	0.117	0.083	0.08	0.093	0.091	0.275	0.28	0.279	0.287	0.272

Source: Results estimates

Note: The standard errors are in parentheses: *, ** and *** denote coefficients that are significant at 10%, 5% and 1% respectively

Table 7.13 Allocative efficiency estimates for linear, tobit, logit and selected fractional regression models

One-part models					Two-part models						
					1st Part		2nd Part				
	Linear	**Tobit**	**logit**	**Cloglog**	**logit**	**Cloglog**	**Linear**	**logit**	**probit**	**loglog**	**cloglog**
Intercept	0.498*** (0.114)	0.503*** (0.114)	0.005 (0.507)	-0.460 (0.371)	-2.133 (3.541)	-2.123 (3.280)	0.485*** (0.107)	-0.062 (0.507)	-0.038 (0.311)	0.415 (0.333)	-0.525 (0.379)
Age	0.004* (0.003)	0.005* (0.003)	0.019 (0.013)	0.018** (0.008)	0.095* (0.054)	0.091* (0.047)	0.002 (0.003)	0.007 (0.013)	0.001 (0.007)	0.002 (0.009)	0.008 (0.010)
Experience	-0.006 (0.006)	-0.007 (0.006)	-0.027 (0.020)	-0.022 (0.015)	-0.174 (0.369)	-0.173 (0.162)	-0.004 (0.006)	0.002 (0.018)	0.001 (0.012)	-0.012 (0.012)	-0.015 (0.015)
Energy type	0.240*** (0.042)	0.243*** (0.042)	1.010*** (0.177)	0.735*** (0.127)	2.666 (1.841)	0.272 (1.163)	0.219*** (0.040)	0.924*** (0.166)	0.573*** (0.102)	0.632*** (0.102)	0.688*** (0.122)
Household members	-0.005 (0.015)	-0.008 (0.015)	-0.021 (0.072)	-0.031 (0.049)	-0.643 (0.447)	-0.611 (0.405)	0.009 (0.015)	0.039 (0.073)	0.025 (0.045)	0.036 (0.048)	0.018 (0.054)
School	-0.019** (0.008)	-0.020** (0.008)	-0.082** (0.036)	-0.059** (0.026)	-0.551 (0.405)	-0.498 (0.364)	-0.014* (0.008)	-0.059 (0.037)	-0.037 (0.023)	-0.042* (0.023)	-0.041 (0.028)
Servicing	-0.002* (0.001)	-0.002 (0.001)	-0.009* (0.005)	-0.007 (0.004)	0.088 (0.054)	0.075 (0.048)	-0.003** (0.001)	-0.013*** (0.004)	-0.008*** (0.003)	-0.009*** (0.003)	-0.010*** (0.003)
Years of mill use	-0.008 (0.006)	-0.009 (0.006)	-0.035 (0.024)	-0.025 (0.019)	-0.177 (0.365)	-0.131 (0.361)	-0.006 (0.006)	-0.026 (0.022)	-0.016 (0.014)	-0.019 (0.014)	-0.018 (0.018)
Sigma		0.214*** (0.014)									
Number of observations	116	116	116	116	116	116	112	112	112	112	112
R-squared	0.290	1.730	0.289	0.292	0.21	0.251	0.281	0.281	0.281	0.281	0.282

Source: Results estimates

Note: The standard errors are in parentheses: *, ** and *** denote coefficients that are significant at 10%, 5% and 1% respectively

Table 7.14 Cost-efficiency estimates from the linear, tobit, logit and selected fractional regression models

	One-part models				Two-part models						
					1st Part		2nd Part				
	Linear	**Tobit**	**logit**	**Cloglog**	**logit**	**Cloglog**	**Linear**	**logit**	**probit**	**loglog**	**cloglog**
Intercept	0.443*** (0.094)	0.437*** (0.092)	-0.210 (0.447)	-0.518 (0.354)	-2.133 (3.541)	-2.123 (3.280)	0.427*** (0.079)	-0.284 (0.482)	-0.174 (0.276)	0.188 (0.269)	-0.602 (0.374)
Age	0.005** (0.002)	0.006** (0.002)	0.024** (0.011)	0.021*** (0.008)	0.095* (0.054)	0.091* (0.047)	0.003 (0.002)	-0.001 (0.011)	0.007 (0.005)	0.006 (0.005)	0.011 (0.007)
Experience	-0.004 (0.005)	-0.003 (0.005)	-0.017 (0.020)	-0.015 (0.016)	-0.174 (0.369)	-0.202 (0.390)	-0.002 (0.004)	-0.006 (0.020)	-0.005 (0.011)	-0.005 (0.012)	-0.007 (0.016)
Energy type	0.179*** (0.035)	0.180*** (0.034)	0.807*** (0.143)	0.631*** (0.111)	2.666 (1.841)	2.329 (1.673)	0.152*** (0.030)	0.699*** (0.190)	0.427*** (0.075)	0.431*** (0.077)	0.563*** (0.098)
Household members	-0.025** (0.012)	-0.025** (0.012)	-0.109 (0.067)	-0.095** (0.047)	-0.643 (0.446)	-0.611 (0.405)	-0.010 (0.011)	-0.047 (0.061)	-0.027 (0.037)	-0.022 (0.037)	-0.043 (0.048)
School	-0.021*** (0.007)	-0.021** (0.006)	-0.096*** (0.032)	-0.078*** (0.025)	-0.550 (0.405)	-0.498 (0.364)	-0.015** (0.006)	-0.072** (0.032)	-0.044** (0.019)	-0.044** (0.018)	-0.058** (0.027)
Servicing	-0.000 (0.001)	-0.000 (0.001)	0.000 (0.005)	-0.000 (0.004)	0.088 (0.054)	0.075 (0.048)	-0.001 (0.001)	-0.006** (0.003)	-0.004** (0.002)	-0.004** (0.002)	-0.005** (0.003)
Years of mill use	-0.009* (0.005)	-0.009* (0.005)	-0.042* (0.023)	-0.033* (0.019)	-0.178 (0.365)	-0.131 (0.361)	-0.006 (0.004)	-0.029 (0.020)	-0.018 (0.012)	-0.018 (0.011)	-0.023 (0.017)
Sigma		0.173*** (0.011)									
Number of observations	122	122	116	116	116	116	112	112	112	112	112
R-squared	0.292	-1.122	0.298	0.302	0.21	0.302	0.259	0.258	0.258	0.258	0.257

Source: Results estimates

Note: The standard errors are in parentheses: *, ** and *** denote coefficients that are significant at 10%, 5% and 1% respectively.

7.3.4 Conclusion and recommendations

The efficiency of a sample of 116 rice millers was measured using DEA. Results indicated that the mills were moderately technically inefficient and suffered from substantial cost and allocative inefficiencies.

The technical, cost and allocative efficiencies were on average 0.832, 0.346 and 0.444 respectively. The results imply that output can be increased by 16.8%, 65.4% and 55.6% respectively by using inputs optimally, reducing costs and by minimising improper allocation of inputs given their input prices. The millers had moderate environmental efficiency at 76.4%, implying a potential to reduce emissions by 23.6% by using energy efficiently. Labour, fuel and machine hours were over utilised by 37.07%, 93.1% and 92.24% of the mills respectively. The efficiency determinants included millers' years of schooling, the number of servicing and energy type.

Thus, to increase rice milling efficiency, the rice millers must improve their allocative, scale and cost-efficiency. A policy that empowers the millers with the required skills to enable them to utilise the resources efficiently would therefore be highly beneficial since extension services for millers does not exist in Kenya. As well, policy that addresses the knowledge gap in servicing and maintaining the mills through training millers on handling and maintenance of the rice processing machines would help reduce inefficiency. In the study area, mill maintenance is often done either by the owner or operator - an informal skill they acquire while running the milling business. Last, providing access to a reliable and clean source of energy will also help the millers improve the milling and environmental efficiency by reducing carbon dioxide emissions from energy use.

7.4 RICE PROCESSING EFFICIENCIES FOR FARMERS/MILLERS

7.4.1 Technical efficiency scores of standard and network DEA

Table 7.15 provides the traditional and network DEA efficiency scores while Table 7.16 presents the network DEA efficiency scores for each mill.

The drying and milling sub-processes efficiency scores were 0.717 and 0.607 respectively with a range of 0.121 to 1.0. The overall mean processing efficiency under network DEA was 0.662 with a range of 0.36 to 1 while for the black box model the efficiency level was 0.809 with a range of 0.44 to 1.0. The results imply that if the average sample mill operates at maximum efficiency, then it would reduce its drying labour by 29.3% and 39.3% of its milling inputs on average. Overall, on average, there was possibility of reducing inputs by 33.8% and 19.1% under the network DEA and traditional DEA respectively.

The network DEA scores were generally lower than the standard DEA scores, which highlight the network DEA's greater discriminatory power compared with the standard DEA technique. As observed from the results, under the network DEA and black box approaches three and seven mills respectively were fully efficient, with the inefficient mills under network DEA also being inefficient in at least one or all the sub-processes. For the drying sub-process, only seven mills were fully efficient. The results suggest that by ignoring the drying sub-process in a post-harvest process and measuring efficiency only by the milling process thus exaggerates the results. Such exaggerated results can lead to adopting flawed policies and a costly misallocation of resources which developing countries such as Kenya can least afford.

Thus, this study reveals the importance of using the network DEA, which captures all the sub-processes.

Table 7.15 Summary of technical efficiency estimates

	Drying sub-process		Milling sub-process		Network DEA efficiency		Traditional DEA efficiency	
Range	**No of mills**	**% of mills**	**No of mills**	**% of mills**	**No of mills**	**% of mills**	**No of mills**	**% of mills**
<0.1	0	0	0	0	0	0	0	0
0.11-0.199	0	0	1	3.85	0	0	0	0
0.20-0.299	0	0	2	7.69	0	0	0	0
0.30-0.399	3	11.54	3	11.54	1	3.85	0	0
0.40-0.499	0	0	7	26.92	3	11.54	1	3.85
0.50-0.599	3	11.54	2	7.69	8	30.77	5	19.23
0.60-0.699	5	19.23	1	3.85	3	11.54	5	19.23
0.70-0.799	8	30.77	2	7.69	4	15.38	2	7.69
0.80-0.899	0	0	1	3.85	4	15.38	0	0
0.9-0.999	0	0	0	0.00	0	0.00	0	0
1.00	7	26.92	7	26.92	3	11.54	13	50
Average		0.717		0.607		0.662		0.809
Minimum		0.300		0.121		0.360		0.440
Maximum		1.000		1.000		1.000		1.000
Std. Dev		0.216		0.286		0.184		0.206

Source: Results estimates

Table 7.16 Summary results of the efficiency scores for rice millers

	Network DEA Model			Black Box Model
DMU	**Node 1 (Drying)**	**Node 2 (Milling)**	**Overall Score**	**Overall Score**
1	0.376	0.634	0.505	0.674
2	0.602	0.402	0.502	1.000
3	1.000	0.359	0.679	0.762
4	1.000	0.504	0.752	1.000
5	0.500	0.430	0.465	0.548
6	0.753	0.295	0.524	0.532
7	0.751	0.295	0.523	0.562
8	0.764	0.121	0.443	0.440
9	1.000	0.416	0.708	0.792
10	0.600	0.860	0.730	1.000
11	0.549	0.347	0.448	1.000
12	1.000	1.000	1.000	1.000
13	0.750	0.451	0.600	0.677
14	0.762	0.342	0.552	0.552
15	0.600	1.000	0.800	1.000
16	0.750	0.527	0.639	0.615
17	0.750	1.000	0.875	1.000
18	0.600	1.000	0.800	1.000
19	0.375	0.769	0.572	1.000
20	0.600	0.497	0.549	0.647
21	1.000	1.000	1.000	1.000
22	1.000	1.000	1.000	1.000
23	1.000	0.704	0.852	1.000
24	0.500	1.000	0.750	1.000
25	0.750	0.411	0.580	0.660
26	0.300	0.419	0.360	0.578
Average	0.717	0.607	0.662	0.809
Minimum	0.300	0.121	0.360	0.440
Maximum	1.000	1.000	1.000	1.000
Std. Dev	0.216	0.286	0.184	0.206

Source: Results estimates

7.4.2 Input inefficiency ratio

Table 7.17 provides the input excess or shortfall for the mills. The results reveal excess input use in all the sub-processes.

Table 7.18 provides the input use ratios for each mill, which compare the cost-efficiency input minimising levels with the technical efficiency input levels. A ratio greater than one implies input overuse while a ratio less than one suggests input shortage. Drying labour was used excessively in almost three quarters of the mills (73.1%) with 30.8% utilising it optimally. In the milling, sub-process, 56.7% of the mills had excess labour, while 42.3% used it optimally. The two key reasons for labour overuse include first, the fact that although the mills were small they supported an average of two workers as observed from the means. Second, due to the absence of other economic activities in Mwea, the labour overuse indicates the existence of disguised unemployment. Furthermore, in the absence of drying machines, the drying process including turning the paddy over regularly and threshing is done by manual labour. Machinery that would perform this task could reduce the labour excess and eventually reduce costs.

In the milling, sub-process, the mill hours were optimal in 30.8% of the mills while 69.2% operated excess hours. Excess mill hours include the times when milling stopped due to servicing or when the mills broke down, which thus explains the excess hours. 73.1% of the mills over utilised energy while 26.9% used energy optimally. The excess use of energy may be due to mill inefficiency because of the mill's age. With most the examined mills using electricity, this is also likely to contribute to inefficiency due to Kenya's power supply being highly unreliable with frequent blackouts. Thus, improving the mills' efficiency by reducing machine hours, as well as energy and labour excesses, can significantly reduce costs.

The amount of paddy processed was in excess in 38.5% of the mills, while 26.9% utilised paddy optimally. There was a paddy shortfall in 34.6% of the mills had. An excess of 38.5% indicates a substantial paddy wastage which reduces the amount of rice output from the milling process. Measures to reduce this waste would clearly increase efficiency. The mills with a paddy shortfall could also improve efficiency by increasing the amount of paddy they process.

Table 7.17 Input excess or shortfall

DMU	Labour (Drying)	Labour (Milling)	Machine (Hrs)	Energy	Paddy
1	-4.93	0	-2054.46	-3879.65	0
2	-1.99	-4.70	-885.14	-5410.17	0
3	0	-1.93	-2795.34	-5251.52	0
4	0	-0.81	-2150.75	-2703.16	0
5	-3	-2.91	-2168.37	-1609.19	0
6	-1.00	-8.69	-882.43	-58207.84	0
7	-1.00	-4.78	-2146.69	-9151.46	0
8	-0.94	-28.23	-5795.73	-48273.09	0
9	0	-0.90	-2166.68	-9332.73	0
10	-2	0	-533.99	-543.58	0
11	-2.71	-39.91	-405.47	-62939.12	0
12	0	0	0	0	0
13	-1	-1.84	-908.92	-6665.53	0
14	-0.95	-5.32	-824.88	-71935.59	0
15	-2	0	0	0	0
16	-1	-0.97	-306.53	-16918.44	0
17	-1	0	0	0	0
18	-2	0	0	0	118950
19	-5	0	0	-29405.49	66911.83
20	-2	-1	-312	-45819.80	29000
21	0	0	0	0	0
22	0	0	0	0	0
23	0	0	-309.02	-3184.64	425.94
24	-4	0	0	0	0
25	-1	-0.98	-1555.94	-20040.81	0
26	-7	-0.95	-1552.18	-15623.88	0

Source: Network DEA estimates

Note: The negative sign implies an excess while the positive figures imply a shortfall

Table 7.18 Individual input ratios

DMU	Milling Labour	Drying Labour	Machine hours	Energy	Rice output	Paddy
1	1.00	2.66	2.22	2.22	1.00	1.03
2	3.05	1.66	1.55	4.28	1.00	0.80
3	1.93	1.00	2.78	5.07	1.00	1.04
4	1.37	1.00	2.35	2.82	1.00	1.02
5	2.39	2.00	2.38	2.22	1.00	1.27
6	4.76	1.33	1.55	35.75	1.00	1.02
7	3.16	1.33	2.34	7.01	1.00	1.09
8	11.19	1.31	4.42	21.02	1.00	1.03
9	1.43	1.00	2.37	7.99	1.00	1.04
10	1.00	1.67	1.32	1.21	1.00	0.95
11	8.84	1.82	1.19	11.25	1.00	0.83
12	1.00	1.00	1.00	1.00	1.00	1.00
13	1.85	1.33	1.57	5.67	1.00	0.99
14	4.17	1.31	1.49	8.65	1.00	1.03
15	1.00	1.67	1.00	1.00	1.00	1.00
16	1.48	1.33	1.20	14.82	1.00	1.54
17	1.00	1.33	1.00	1.00	1.00	1.00
18	1.00	1.67	1.00	1.00	0.25	0.30
19	1.00	2.67	1.00	3.25	0.16	0.20
20	2.00	1.67	1.20	6.32	0.55	0.67
21	1.00	1.00	1.00	1.00	1.00	1.00
22	1.00	1.00	1.00	1.00	1.00	1.00
23	1.00	1.00	1.20	3.61	0.99	1.00
24	1.00	2.00	1.00	1.00	1.00	1.00
25	1.48	1.33	1.99	17.55	1.00	0.86
26	1.47	3.33	1.99	13.54	1.00	0.85
Efficient	42.31%	26.92%	30.77%	26.92%	84.62%	26.92%
Excess	57.69%	73.08%	69.23%	73.08%	0%	38.46%
Shortfall	0%	0%	0%	0%	15.38%	34.62%

Source: Network DEA estimates

7.4.3 Technical inefficiency estimates

7.4.3.1 Determinants of efficiency of the drying sub-process

Table 7.19 provides the estimated coefficients for the inefficiency models for the stage one (drying sub-process).

In the one-part models, at 10% significance level, millers' gender and storage area coefficients were statistically significant while age, experience and the distance of the mill from the market did not affect efficiency since the variables were not significant.

In the first part of the two-part models, at a 10% significance level, the gender of the miller and distance of the mill from the market explain the efficiency of the mills while at 5% significance level, the storage area was positively correlated with efficiency scores using the logit model. Using the cloglog model at a 5% significance level, the distance of the mill from the market explains why some mills were efficient while at a 1% significance level, the storage area was positively associated with efficiency scores.

The negative impact between the millers' gender and efficiency implies that males tend to be more inefficient when it comes to drying than the females. This finding contradicts the bulk of existing literature that finds males more efficient than females. For example, Ironkwe, et al. (2014) in their study on cassava farming in Akwa Ibom State, Nigeria, established that the males had higher technical efficiency than the females. Oladeebo (2012), also found poor female-headed households to be less efficient in contrast with the poor-male-headed households who were more efficient. The role of females in paddy post-harvest handling remains critical since they spend more time on paddy threshing, storage, cleaning and drying than the males. The results suggest that women tend to be keener with the paddy process in contrast to men.

The storage area results were found to be positively associated with the drying process efficiency at a 10% significance level. Paddy storage remains critical especially during and after drying. Wilson et al. (1998) found a positive association between storage of potatoes after harvest and efficiency in the United Kingdom. Therefore, adequate and appropriate space for paddy storage becomes important since it can prevent or discourage the growth of microorganisms and insects, avoid exposure of the paddy to contaminants such as dust, vermin's, leaves, sand and other foreign objects. Storage also shelters the paddy from varying temperature levels and wind which can lower its quality. Traditional paddy storage in Kenya involves putting it in granaries or within the house. Although this type of storage area may not provide the necessary conditions for example the right moisture and temperature conditions required for the grain it is still better than in situations where no storage area exists.

The market distance was negatively associated with technical efficiency. This finding backs similar studies that have found that increased market distance led to a decline of a farm's technical efficiency. Bagamba et al. (2007) and Sibiko et al. (2013) found that farms located farther from the market incur more costs in transporting their inputs and outputs compared to those close to the market among smallholder banana producers and common bean farmers in Uganda. Apart from the transport costs incurred, paddy is typically carried using donkey carts in the Mwea region due to the poor road network, posing a high risk of the product being exposed to rainfall, varying temperatures and dust.

In terms of efficiency of the mills, in the second part of the two-part models, it is revealed that storage space had a positive relationship with efficiency scores for both the full efficient and the inefficient millers. The miller's age, their experience level and distance of the mill from the market did not explain the efficiency of the mills, since these results were not significant. However, gender had a negative association with efficiency scores among the inefficient mills which indicates that being male increased inefficiency than being female among the inefficient mills.

Thus, policies that would encourage access to cheap and affordable means of paddy storage such as adoption of simple silos would be beneficial to the millers. Educating male millers on post-harvest paddy handling is also recommended to reduce their inefficiency. Improving the poor road network in Mwea region will help improve the speed of delivery of paddy to the market hence reducing inefficiency.

Table 7.19 Results for linear, tobit, logit and selected fractional regression models

	One-part models				**Two-part models**						
					1st Part		**2nd Part**				
	Linear	**Tobit**	**logit**	**cloglog**	**logit**	**cloglog**	**Linear**	**logit**	**probit**	**loglog**	**cloglog**
Intercept	1.009*** (0.160)	1.140*** (0.193)	2.410** (1.050)	1.006* (0.591)	5.810* (3.331)	3.438 (2.156)	0.578*** (0.164)	0.300 (0.698)	0.190 (0.429)	0.594 (0.561)	-0.154 (0.437)
Age	-0.005 (0.004)	-0.008 (0.005)	-0.027 (0.022)	-0.014 (0.013)	-0.159 (0.102)	-0.107 (0.074)	0.002 (0.004)	0.009 (0.014)	0.006 (0.009)	0.007 (0.012)	0.006 (0.009)
Distance	-0.002 (0.002)	-0.003 (0.003)	-0.011* (0.006)	-0.006** (0.003)	-0.545 (0.583)	-0.470 (0.462)	-0.002 (0.003)	-0.010 (0.006)	-0.006 (0.004)	-0.008* (0.005)	-0.006 (0.004)
Experience	-0.008 (0.010)	-0.009 (0.011)	-0.039 (0.031)	-0.020 (0.019)	-0.160 (0.234)	-0.123 (0.183)	-0.003 (0.008)	-0.012 (0.026)	-0.007 (0.016)	-0.011 (0.021)	-0.007 (0.017)
Gender	-0.150* (0.096)	-0.173* (0.112)	-0.722* (0.389)	-0.395 (0.249)	-1.404 (1.713)	-0.779 (1.150)	-0.120 (0.083)	-0.498* (0.294)	-0.310* (0.183)	-0.383* (0.224)	-0.333* (0.200)
Storage	0.000* (0.000)	0.000* (0.000)	0.000** (0.000)	0.000*** (0.000)	0.001* (0.001)	0.001** (0.000)	0.000 (0.000)	0.000** (0.000)	0.000** (0.000)	0.000** (0.000)	0.000** (0.000)
Sigma		0.222*** (0.039)									
Number of observations	26	26	26	26	26	26	19	19	19	19	19
R-squared	0.345	0.544	0.367	0.351	0.36	0.352	0.268	0.271	0.27	0.273	0.268

Source: Results estimates

Note: The standard errors are in parentheses: *, ** and *** denote coefficients that are significant at 10%, 5% and 1% respectively

7.4.3.2 Determinants of efficiency of the milling sub-process

Table 7.20 provides the milling sub-process efficiency determinants. For the one-part models, years of schooling, millers' experience, the number of times the mill was serviced and age of the mill were significant at 5% significance level while energy type did not affect efficiency in all the linear models. At 5% significance level, the years of experience had a positive sign and was significant which implies that experience enhanced millers' efficiency. The finding coincides with other existing studies such as that of Foster and Rosenzweig (1995) who argue that experience raises the farmers' ability to make better decisions on input use for new technologies. Lohr and Park (2006) also found the years of experience to contribute positively towards farm performance among US organic farmers.

The number of times the mill was serviced had a negative impact on efficiency at the 5% significance level. The negative impact between the number of times the mill was serviced and efficiency scores is attributed to the improper maintenance of machines which lead to losses since the mills become less productive (Subramaniam, et al., 2008). During the survey, the millers indicated that servicing included changing and greasing parts such as sieves when required and mill repairs due to breakdowns all of which leads to unwanted wastages due to machine stoppages.

The age of the mill coefficient was negatively associated with technical efficiency since the variable at 5% significance level which implies mill performance declines with age. Gunatilake and Gopalakrishnan (2010) also found a negative relationship between saw milling machinery age and efficiency scores among sawmills in Sri Lanka which reinforces the above finding.

At 10% significance level, the years of schooling coefficient was negative and significant, meaning that inefficiency increases with increased years of schooling. The negative association between the years of schooling and efficiency scores contradicts the bulk of existing literature but reinforces the findings by Fleming and Lummani (2001) and Kalirajan and Shand (1985), who found a negative association between education and technical efficiency. Considering that the technology the millers are using is not modern (old mills), it is possible that the effect of education on milling may not be effective under such unmodernised technology. Patrick and Kehrberg (1973) found schooling returns to be negative or low in agricultural areas of Eastern Brazil but gradually increased with the level of modernisation.

In the first part of the two-part models, all the variables were insignificant except the millers' experience which explained the mills' full efficiency. However, in the second part, the millers' number of years of schooling and the number of times the mill was serviced explain the mills' inefficiency.

Table 7.20 Results for linear, tobit, logit and selected fractional regression models

	One-part models				Two-part models						
					1st Part		2nd Part				
	Linear	**Tobit**	**logit**	**cloglog**	**logit**	**cloglog**	**Linear**	**logit**	**probit**	**loglog**	**cloglog**
Intercept	1.134*** (0.231)	1.307*** (0.282)	2.944*** (0.915)	1.548*** (0.553)	3.262 (2.979)	2.139 (2.294)	0.801*** (0.198)	1.239** (0.547)	0.772** (0.338)	1.209*** (0.380)	0.562 (0.404)
Energy (0,1)	-0.169 (0.120)	-0.252* (0.149)	-0.914 (0.653)	-0.473 (0.390)	-1.951 (1.333)	-1.240 (0.867)	-0.025 (0.110)	-0.104 (0.214)	-0.065 (0.132)	-0.079 (0.146)	-0.067 (0.159)
Experience (yrs)	0.036** (0.018)	0.047** (0.021)	0.176* (0.094)	0.098* (0.059)	0.425* (0.241)	0.272 (0.184)	0.004 (0.015)	0.015 (0.030)	0.010 (0.019)	0.013 (0.020)	0.009 (0.024)
School (yrs)	-0.029 (0.019)	-0.034* (0.022)	-0.129** (0.057)	-0.091** (0.039)	-0.259 (0.261)	-0.219 (0.216)	-0.020 (0.014)	-0.078* (0.043)	-0.049* (0.027)	-0.055 (0.030)	-0.057* (0.032)
Number of Servicing	-0.004** (0.002)	-0.005** (0.002)	-0.019*** (0.006)	-0.011** (0.005)	-0.024 (0.024)	-0.014 (0.019)	-0.002* (0.001)	-0.010*** (0.004)	-0.006 (0.002)	-0.006*** (0.002)	-0.008** (0.003)
Years of mill use	-0.022** (0.010)	-0.029** (0.012)	-0.106** (0.046)	-0.062** (0.028)	-0.268 (0.181)	-0.181 (0.136)	-0.005 (0.008)	-0.019 (0.017)	-0.012 (0.011)	-0.013** (0.012)	-0.014 (0.013)
Sigma		0.285*** (0.050)									
Number of observations	26	26	26	26	26	26	19	19	19	19	19
R-squared	0.394	0.378	0.418	0.412	0.272	0.232	0.359	0.376	0.372	0.354	0.392

Source: Results estimates

Note: The standard errors are in parentheses: *, ** and *** denote coefficients that are significant at 10%, 5% and 1% respectively

7.4.4 Conclusion and recommendations

The efficiency of 26 rice millers was assessed using the traditional DEA and network DEA. The average technical efficiency of the milling sub-process was 0.607 while that of the drying sub-process was 0.717. The overall average technical efficiency of the two processes under network DEA was 0.662 while that of the traditional DEA (black box) approach, where the milling sub-process is ignored in the analysis was 0.809. Thus, the network DEA model had lower efficiency scores than the traditional DEA model which implies that analysing efficiency using the network DEA gives results that have a greater discriminatory power than those of the traditional approach.

In terms of labour use for the drying sub-process, 73.1% of the mills used excess labour and only 26.9% utilised drying labour efficiently. For the milling, sub-process, 69.2% of the mills used excess machine hours while only 30.8% of the mills utilised machine hours efficiently. In the milling-sub-process, 73.1% of the mills over utilised energy while 26.9% utilised energy efficiently. Excess labour was found in 57.7% of the mills with 42.3% of the mills having optimal labour use. Rice output shortage was evident in 15.4% of the mills with 84.6% of the mills being efficient in this area. Excess paddy was found in 38.5% of the mills, 26.9% utilised paddy efficiently while 34.6% had paddy shortfall.

Based on the findings, reducing machine hours, energy and labour would help enhance the average technical efficiency of the mills. The drying sub-process in all the mills being labour oriented explained the excessive labour use in the drying sub-process. Drying of paddy is often done in the open air and on the ground under the sun, which translates to no cost to the miller. However, this method exposes the paddy to contaminants such as dust, vermin, leaves, sand and other foreign objects. This process also exposes the paddy to varying temperature levels and the wind which may mean under-drying or over-drying which lowers the quality. Thus, simple drying machines would reduce the labour excess in the drying sub-process and maintain the paddy quality hence enhancing drying efficiency.

The determinants of the drying sub-process included distance of the mill from the market, miller gender and availability of storage space. The determinants of the milling sub-process included: energy type, millers' experience, millers' schooling level, the number of times the mill was serviced and the age of the mill (years of mill use).

Thus, based on these findings, policy-makers should focus on the following. First, they should help enhance millers' access to better and newer milling technologies to improve technical efficiency. Second, policies should promote millers' access to a reliable source of energy such as solar, which can help improve their milling efficiency. Third, providing training especially on post-harvest handling of paddy including drying and storage will help improve the quality of processed rice. Last, enhancing millers' access to simple drying machines can contribute to reducing technical inefficiency in drying.

Chapter 8: Conclusions

8.1 CONCLUSIONS FROM THE STUDIES

The thesis is comprised of two-parts. The first part focuses on African agricultural productivity analysis using a sample of twenty-seven countries. Agricultural productivity is found to be low and considerably lower in the presence of bad outputs. Efficiency change has driven African agricultural productivity through increased input use and expanding land area rather than from changes in technology.

The results provide important policy implications since expanding the land area will no longer be feasible with the rapid shrinking of African farm sizes. The low mix efficiency implies that countries have failed to attain optimal scale and scope of operations and the right combination of inputs or outputs. The distribution of productivity change and its components was found to be the same across the groups of countries for MI model, while the comparison of MI and MLI productivity estimates and their components were found to differ across the categories of groups, which indicates that the two indexes were significantly different. This implies that excluding undesirable outputs in any productivity estimation would yield biased results in productivity change, efficiency change and technical change.

The determinants of TFP were agriculture R&D spending, area irrigated, political stability, average years of schooling (of adults), per capital land and ratio of HIV prevalent adults. The MI, MLI and FPI are used for comparison purposes and to assess the analytical strength of each method. The FPI is favoured since it decomposes productivity into finer components of technical change, technical efficiency however it assigns equal weights to good and bad outputs. The MLI is superior when it comes to bad outputs because it assigns negative weights to the undesirable outputs and corresponds with the MI when the bad outputs are not included.

The second part of the thesis examines rice farming and processing efficiency in Kenya, given the growing demand for rice and the country's growing dependence on imports to satisfy local demand. Rice farming efficiencies are low mainly due to cost and allocative inefficiency. The technical efficiency determinants of rice farming include age, rice farmer gender, humidity, rainfall, temperature and adopting of technologies while age, experience, rice farmer gender, rice farming region and adoption of technologies had an impact on allocative efficiency. Cost-efficiency determinants include age of the farmer, rice farmer gender and experience.

Low efficiency among rice millers only is in large part due to cost and allocative inefficiency. However, environmental efficiency of the millers is moderately high when bad outputs are considered in the analysis. The technical efficiency determinants include energy type used, total adult household members and the number of time the mill was serviced. Allocative efficiency determinants include age of the miller, energy type, years of schooling and the number of mill servicing. Cost-efficiency determinants include age of the miller, energy type, number of household members, millers' schooling level, the age of the mill and the number of times the mill was serviced. The rice milling and drying sub-processes are moderately efficient with the efficiency scores being much higher for the traditional DEA (black box DEA) than with the network DEA approach. The drying sub-process determinants include how far the mill was located from the market, the gender of the miller and availability of storage space. In the milling-sub-process, the factors affecting efficiency include energy type, millers' experience, schooling level of the miller, the number of mill servicing and age of the mill (number of years used).

8.2 POLICY RECOMMENDATIONS

Based on the findings of productivity analysis of African Agriculture, the thesis recommends that there is need for policy makers in Africa to put in place policies that would improve access to education since education has the potential of improving agricultural productivity. Policies that would improve political stability and enhance good governance would help improve agricultural productivity. Due to volatile weather conditions experienced by many African countries, introducing policies which strengthen water resources such as conservation and water harvesting would in the long run improve agricultural productivity.

Enacting land and property rights policies would encourage intensification rather than expansion of cultivated land area would help bring about equitable agricultural productivity growth. This will also reduce the pressure of moving to marginal lands hence curbing land degradation. Policies that would encourage adoption of agricultural technologies such as use of improved seed varieties, quality livestock breeds and inorganic fertilisers by the farmers would help boost agricultural productivity. The results also indicate the benefit of increased agricultural research spending which would be critical in spearheading research that would improve agricultural productivity. Hence it is important for the African governments to commit themselves to setting aside 10% of their GDP earnings towards agricultural research as agreed during African Heads of State and Government meeting of August 2013.

Further, policies that would improve access to health care such as through HIV AIDS management and care may likely help to improve human well-being hence leading to a positive impact on agricultural productivity. Promoting strategies that help reallocate resources from producing bad outputs to producing good outputs will be beneficial to the farmers and will bring about environmental sustainability. For example, policies that encourage efficient use of manure and fertiliser would help improve soil and crop productivity.

On rice farming and processing in Kenya, the thesis recommends the following measures. First, policy interventions should aim at improving overall technical, cost and allocative efficiency of rice farming. Specifically, policy-makers should focus on enhancing the efficiency of rice farmers with better technologies and training in-order to reduce the inefficiency. The policy measures should include adaptive strategies that would mitigate adverse effects of climatic factors. Second, policies that would help farmers diversify to short-time horticultural crops such as tomatoes, watermelons or beans especially during the fallow months would help the farmers enhance their livelihoods. Third, policies that address the challenges of age and gender related issues in rice farming to bridge the technical efficiency gap of older farmers and young farmers and between male and female farmers would be beneficial. Fourth, market and trade policies which would reduce the transaction costs of rice farming, especially in the Western Schemes and which would help narrow the efficiency gap between Mwea and the Western regions should be adopted. Fifth, the very inefficient rice farmers should be encouraged to exit the industry thereby allowing policy-makers to reallocate the resources (especially land and water) to other economic activities. Sixth, policies that enhance millers' access to better and newer milling technologies to such as simple drying machines would increase the technical efficiency of the millers.

Other beneficial policies include improving access to other reliable and cheaper sources of energy such as solar would reduce the milling inefficiency and environmental pollution. Providing training especially on post-harvest handling of paddy including drying and storage would contribute to improving the quality of processed rice.

8.3 LIMITATIONS OF THE STUDIES

The thesis examined African agricultural productivity for twenty-seven countries for the period 1980-2012, and rice farming and processing in Kenya for the period 2013/2014. The study does have some limitations.

The first part of the thesis focused on productivity analysis of only half of the countries i.e. 27 out of the 54 African countries due to data limitation. The thesis aimed to use a balanced panel dataset and therefore included only the twenty-seven countries for which complete data was available. The second part of the thesis examined rice farming and processing in Kenya based on a single year questionnaire, which means it reflected only the situation between 2013 and 2014. Thus, the study does not capture effects such as technological catch-up, technical change or capital accumulation over time (Mugera & Featherstone, 2008).

The study was limited to Kenya's four major irrigation schemes and Mwea rice millers. Due to funding constraints and time, the prospects of a repeat survey to form a panel data became infeasible. The study did not cover rice farmers and processors located in the coastal area due to threats of Al-Shabaab terrorist attacks at the time of the survey. Although there may be other rice processing mills scattered around Kenya, they were not studied due to funding constraints.

8.4 RECOMMENDATIONS FOR FURTHER RESEARCH

The thesis recommends the following for further research:

To understand the recent African agricultural productivity trends, extending the analysis to cover more countries subject to data being available is recommended. The FPI decomposed productivity into TFP change and its finer components of technical, scale and mix efficiencies, however, it is acknowledged that the model was not able to incorporate undesirable outputs because it gives positive weights. Thus, the FPI can be improved to cater for the analysis of undesirable output which was beyond the scope of the thesis.

Concerning Kenyan rice farming and processing of Kenya, the thesis recommends the following. First, extension of the study period to cover panel data would help reflect beneficial changes in rice technological catch-up, technical change and capital accumulation over time (Mugera & Featherstone, 2008). Second, further research should aim at comparing rice farming and processing across Kenya to cover such areas such as the coastal region (Tana Delta & Msambweni) and Nyanza (Migori & Kuria) and the non-irrigated rice farming areas. Last, it is recommended that the study be extended to cover other African countries given rice is now grown widely in Africa.

Bibliography

AGRA. (2014). *Africa agriculture status report 2014: Climate change and smallholder agriculture in Sub-Saharan Africa*. Alliance for a Green Revolution in Africa (AGRA), Nairobi, Kenya.

Akudugu, M. A., Guo, E., & Dadzie, S. K. (2012). Adoption of modern agricultural production technologies by farm households in Ghana: what factors influence their decisions? *Journal of Biology, Agriculture and Healthcare, 2*(3), 1-13.

Alene, A. D. (2010). Productivity growth and the effects of R&D in African agriculture. *Agricultural Economics, 41*(3 ‐ 4), 223-238.

Ali, J., Singh, S. P., & Ekanem, E. (2009). Efficiency and productivity changes in the Indian food processing industry: determinants and policy implications. *International Food and Agribusiness Management Review, 12*(1), 43-66.

Alston, J. M., Babcock, B. A., & Pardey, P. G. (2010). Shifting patterns of global agricultural productivity: Synthesis and conclusion. *2010): The shifting patterns of global agricultural production and productivity worldwide. Iowa State University: The Midwest Agribusiness Trade Research and Information Center*, 449-482.

Aly, H. Y., Grabowski, R., Pasurka, C., & Rangan, N. (1990). Technical, scale, and allocative efficiencies in US banking: an empirical investigation. *Review of Economics and Statistics, 72*, 211-218.

Aoun, A. (2004). The performance of Tunisian Agriculture: An economic appraisal. *NEW MEDIT., 3*, 4-7.

Areal, F. J., Tiffin, R., & Balcombe, K. G. (2012). Provision of environmental output within a multi-output distance function approach. *Ecological Economics, 78*, 47-54.

Arnade, C. (1998). Using a programming approach to measure international agricultural efficiency and productivity. *Journal of Agricultural Economics, 49*(1), 67-84.

ASTI. (2016). *Agricultural Science and Technology Indicators: 2012 ASTI database*. International Food Policy Research Institute. Retrieved from: http://www.asti.cgiar.org/data.

Atolia, M. (2008). *Productivity-enhancing reforms, private capital inflows, and real interest rates in Africa*. (WP2008-12). Department of Economics, Florida State University, United States of America.

AU. (2013). *Toward African renaiAfricance: Renewed partnership for a unified approach to end hunger in Africa by 2025 under the framework the Comprehensive Africa Agriculture Development Programme. High level meeting of African and international leaders.* 30th June - 1st July 2013, African Union Conference Center, Addis Ababa, Ethiopia.

Avila, A. F. D., & Evenson, R. E. (2010). Total factor productivity growth in agriculture: the role of technological capital. *Handbook of Agricultural Economics, 4*, 3769-3822.

Avkiran, N. K. (2009). Opening the black box of efficiency analysis: an illustration with UAE banks. *Omega*, *37*(4), 930-941.

Ayoub, A. (1999). Land degradation, rainfall variability and food production in the Sahelian zone of the Sudan. *Land Degradation & Development, 10*(5), 489-500.

Bagamba, F., Ruben, R., & Rufino, M. (2007). Determinants of banana productivity and technical efficiency in Uganda. In Smale, M., & Tushemereirwe, W. (Eds.) *An economic assessment of banana genetic improvement and innovation in the Lake Victoria Region of Uganda and Tanzania* (Vol. 155, pp. 109-128). Washington DC: International Food Policy Research Institute.

Baghdadli, I., Harborne, B., & Rajadel, T. (2008). *Breaking the cycle: a strategy for conflict-sensitive rural growth in Burundi*. (Main report No. 147). Washington DC: The World Bank.

Baiphethi, M. N., & Jacobs, P. T. (2009). The contribution of subsistence farming to food security in South Africa. *Agrekon, 48*(4), 459-482.

Balasubramanian, V., Sie, M., Hijmans, R. J., & Otsuka, K. (2007). Increasing rice production in Sub-Saharan Africa: challenges and opportunities. *Advances in Agronomy*, *94*, 55-133.

Balcombe, K., Fraser, I., Latruffe, L., Rahman, M., & Smith, L. (2008). An application of the DEA double bootstrap to examine sources of efficiency in Bangladesh rice farming. *Applied Economics, 40*(15), 1919-1925.

Balk, B. M. (2001). Scale efficiency and productivity change. *Journal of Productivity Analysis, 15*(3), 159-183.

Banaszek, M., & Siebenmorgen, T. (1990). Head rice yield reduction rates caused by moisture adsorption. *Transactions of the ASAE, 33*(4), 1263-1269.

Bandiera, O., & Rasul, I. (2006). Social networks and technology adoption in Northern Mozambique. *Economic Journal, 116*(514), 869-902.

Banful, A. B. (2011). Old problems in the new solutions? Politically motivated allocation of program benefits and the “new” fertilizer subsidies. *World Development, 39*(7), 1166-1176.

Banker, R. D., & Natarajan, R. (2008). Evaluating contextual variables affecting productivity using data envelopment analysis. *Operations Research*, *56*(1), 48-58.

Barnes, A. P. (2006). Does multi-functionality affect technical efficiency? A non-parametric analysis of the Scottish dairy industry. *Journal of Environmental Management, 80*(4), 287-294.

Basorun, J. (2008). A bivariate analysis of factors affecting rice processing in Igbemo-Ekiti, Nigeria. *Agricultural Journal, 3*(6), 442-446.

Bates, R. H., & Block, S. A. (2013). Revisiting African agriculture: institutional change and productivity growth. *Journal of Politics, 75*(2), 372-384.

Belloumi, M., & Matoussi, M. S. (2009). Measuring agricultural productivity growth in MENA countries. *Journal of Development and Agricultural Economics, 1*(4), 103-113.

Benhabib, J., & Spiegel, M. M. (1994). The role of human capital in economic development evidence from aggregate cross-country data. *Journal of Monetary Economics, 34*(2), 143-173.

Benhabib, J., & Spiegel, M. M. (2005). Human capital and technology diffusion. *Handbook of Economic Growth, 1*(A), 935-966.

Benson, T., Mogues, T., & Woldeyohannes, S. (2014). *Assessing progress made toward shared agricultural transformation objectives in Mozambique* (Vol. 1370). Washington DC: International Food Policy Research Institute.

Berry, L. V. (1995). Ghana: A country study (Eds.). Washington DC: Federal Research Division, Library of Congress.

Bijoor, N. S., Czimczik, C. I., Pataki, D. E., & Billings, S. A. (2008). Effects of temperature and fertilization on nitrogen cycling and community composition of an urban lawn. *Global Change Biology, 14*(9), 2119-2131.

Bishwajit, G., Sarker, S., Kpoghomou, M.-A., Gao, H., Jun, L., Yin, D., & Ghosh, S. (2013). Self-sufficiency in rice and food security: a South Asian perspective. *Agriculture & Food Security, 2*(1), 10.

Breman, H., Groot, J. J. R., & van Keulen, H. (2001). Resource limitations in Sahelian agriculture. *Global Environmental Change, 11*(1), 59-68.

Brigatte, H., & Cardoso Teixeira, E. (2011). Determinants of long-term product and total factor productivity of Brazilian agriculture in the period 1974-2005. *Revista de Economia e Sociologia Rural, 49*(4), 815-836.

Briones, R., & Felipe, J. (2013). Agriculture and structural transformation in developing Asia: review and outlook (*Asian Development Bank Economics Working Paper Series* No. 363). Manila, Phillipines: Asian Development Bank

Bruinsma, J. (2003). *World agriculture: towards 2015/2030. an FAO perspective*. London: Earthscan Publications Ltd.

Bunnin, F. O., Guo, Y., & Ren, Y. (2002). Option pricing under model and parameter uncertainty using predictive densities. *Statistics and Computing, 12*(1), 37-44.

Bureau, J.-C., Färe, R., & Grosskopf, S. (1995). A comparison of three nonparametric measures of productivity growth in European and United States agriculture. *Journal of Agricultural Economics, 46*(3), 309-326.

Burton, W., Morrison, A., Maclean, R., & Ruderman, E. (2006). Systematic review of studies of productivity loss due to rheumatoid arthritis. *Occupational Medicine, 56*(1), 18-27.

Calpe, C. (2006). *Rice international commodity profile*. Rome: Food and Agricultural Organization.

Canadell, J., Raupach, M., & Houghton, R. (2009). Anthropogenic CO_2 emissions in Africa. *Biogeosciences, 6*(3), 463-468.

Castellani, D., & Zanfei, A. (2003). Technology gaps, absorptive capacity and the impact of inward investments on productivity of European firms. *Economics of Innovation and New Technology, 12*(6), 555-576.

Castellani, D., & Zanfei, A. (2007). Multinational companies and productivity spillovers: is there a specification error? *Applied Economics Letters, 14*(14), 1047-1051.

Caves, D. W., Christensen, L. R., & Diewert, W. E. (1982). The economic theory of index numbers and the measurement of input, output and productivity. *Econometrica: Journal of the Econometric Society*, *50*(6), 1393-1414.

Cazals, C., Florens, J. P., & Simar, L. (2002). Nonparametric frontier estimation: a robust approach. *Journal of Econometrics*, *106*(1), 1-25.

Chang, H. H., & Wen, F. I. (2011). Off-farm work, technical efficiency and rice production risk in Taiwan. *Agricultural economics*, *42*(2), 269-278.

Chavas, J.-P., Petrie, R., & Roth, M. (2005). Farm household production efficiency: evidence from The Gambia. *American Journal of Agricultural Economics, 87*(1), 160-179.

Chen, P.-C., Yu, M.-M., Chang, C.-C., & Hsu, S.-H. (2008). Total factor productivity growth in China's agricultural sector. *China Economic Review, 19*(4), 580-593.

Chen, S., & Ravallion, M. (2007). Absolute poverty measures for the developing world, 1981–2004. *Proceedings of the National Academy of Sciences, 104*(43), 16757-16762.

Chen, W., & Ding, Y. (2007). Total Factor Productivity in Chinese agriculture: the role of infrastructure. *Frontiers of Economics in China, 2*(2), 212-223.

Chirikos, T. N., & Sear, A. M. (1994). Technical efficiency and the competitive behavior of hospitals. *Socio-Economic Planning Sciences*, *28*(4), 219-227.

Chiu, C.-R., Liou, J.-L., Wu, P.-I., & Fang, C.-L. (2012). Decomposition of the environmental inefficiency of the meta-frontier with undesirable output. *Energy Economics, 34*(5), 1392-1399.

Chiu, Y. H., Lee, J. H., Lu, C. C., Shyu, M. K., & Luo, Z. (2012). The technology gap and efficiency measure in WEC countries: application of the hybrid meta-frontier model. *Energy Policy*, *51*, 349-357.

Chua, C. L., Griffiths, W. E., & O'donnell, C. J. (2001). Bayesian model averaging in consumer demand systems with inequality constraints. *Canadian Journal of Agricultural Economics/Revue canadienne d'agroeconomie*, *49*(3), 269-291.

Chung, Y. H., Färe, R., & Grosskopf, S. (1997). Productivity and undesirable outputs: a directional distance function approach. *Journal of Environmental Management, 51*(3), 229-240.

Coelli, T., Lauwers, L., & Van Huylenbroeck, G. (2007). Environmental efficiency measurement and the materials balance condition. *Journal of Productivity Analysis, 28*(1-2), 3-12.

Coelli, T. J. (1995). Recent developments in frontier modelling and efficiency measurement. *Australian Journal of Agricultural Economics, 39*(3), 219-245.

Coelli, T. J. (1996). Measurement of total factor productivity growth and biases in technological change in Western Australian agriculture. *Journal of Applied Econometrics, 11*(1), 77-91.

Coelli, T., Rahman, S., & Thirtle, C. (2002). Technical, allocative, cost and scale efficiencies in Bangladesh rice cultivation: a non-parametric approach. *Journal of Agricultural Economics*, *53*(3), 607-626.

Coelli, T. J., Prasada Rao, D. S., O'Donnell, C. J., & Battese, G. E. (2005). Productivity and efficiency measurement concepts. *An introduction to efficiency and productivity analysis*, 41-83. NewYork, NY: Springer Science & Business Media.

Coelli, T. J., & Rao, D. S. P. (2005). Total factor productivity growth in agriculture: a malmquist index analysis of 93 countries, 1980–2000. *Agricultural Economics, 32*(1), 115-134.

Coelli, T., Lauwers, L., & Van Huylenbroeck, G. (2007). Environmental efficiency measurement and the materials balance condition. *Journal of Productivity Analysis*, *28*(1-2), 3-12.

Conteh, A.M.H., Yan, X., and Sankoh, F.P (2012) The Influence of price on rice production in Sierra Leone. *Agricultural Sciences, 3*(4), 462-469.

Craig, B. J., Pardey, P. G., & Roseboom, J. (1997). International productivity patterns: accounting for input quality, infrastructure and research. *American Journal of Agricultural Economics*, *79*(4), 1064-1076.

Crawford, E. W., Jayne, T. S., & Kelly, V. A. (2006). *Alternative approaches for promoting fertilizer use in Africa* (Discussion Paper No. 22). Washington DC: Agriculture & Rural Development Department, The World Bank.

Dalrymple, D. G. (1986). *Development and spread of high-yielding rice varieties in developing countries*. (Report No. 7). Washington DC: United States Agency for International Development.

Daraio, C., & Simar, L. (2005). Introducing environmental variables in nonparametric frontier models: a probabilistic approach. *Journal of productivity analysis*, *24*(1), 93-121.

Dawe, D., Pandey, S., & Nelson, A. (2010). Emerging trends and spatial patterns of rice production. In Pandey, S., Byerlee, D., Dawe, D., Dobermann, A., Mohanty, S., Rozelle, S., & Hardy, B. (Eds.) *Rice in the Global Economy: strategic research and policy issues for food security.* Los Baños: Philippines International Rice Research Institute (IRRI).

Deaton, A. (1999). Commodity prices and growth in Africa. *Journal of Economic Perspectives*, *13*(3), 23-40.

Deininger, K. W., & Olinto, P. (2000). *Why liberalization alone has not improved agricultural productivity in Zambia: The role of asset ownership and working capital constraints* (Policy research working paper No. 2302). Washington DC: Policy Research Dissemination Center, The World Bank.

Denny, M., & de Fontenay, A. (1988). Cost pressures and relative productivity in Canadian telecommunications firms. In Dogramaci, A., & Färe, R. (Eds.). *Applications of modern production theory: efficiency and productivity* (pp. 131-148). Netherlands: Springer Science & Business Media.

Dercon, S., & Christiaensen, L. (2011). Consumption risk, technology adoption and poverty traps: evidence from Ethiopia. *Journal of Development Economics, 96*(2), 159-173.

Dessy, S., Ewoudou, J., & Ouellet, I. (2006). *Understanding the Persistent Low Performance of African Agriculture.* Québec, Canada: Department of Economics, Université Laval and CIRPÉE,

Diao, X., Hazell, P., & Thurlow, J. (2010). The role of agriculture in African development. *World Development, 38*(10), 1375-1383.

Diao, X., Hazell, P. B., Resnick, D., & Thurlow, J. (2007). *The role of agriculture in development: implications for Sub-Saharan Africa* (Working paper Vol. 153). Washington DC: International Food Policy Research Institute.

Diao, X., Thurlow, J., Benin, S., & Fan, S. (2012). *Strategies and priorities for African agriculture: economywide perspectives from country studies*. Washington DC: International Food Policy Research Institute.

Druilhe, Z., & Barreiro-Hurlé, J. (2012). *Fertilizer subsidies in Sub-Saharan Africa* (ESA Working paper No. 12-04). Rome: Food and Agriculture Organization.

Duygun, M., Prior, D., Shaban, M., & Tortosa-Ausina, E. (2015). Disentangling the European airline's efficiency puzzle: a network data envelopment analysis approach. *Omega*, 60, 2-14.

Enwerem, V., & Ohajianya, D. (2013). Farm size and technical efficiency of rice farmers in Imo state, Nigeria. *Greener Journal of Agricultural Sciences, 3*(2), 128-136.

Estudillo, J. P., & Otsuka, K. (2010). Rural poverty and income dynamics in Southeast Asia. *Handbook of Agricultural Economics*, *4*, 3435-3468.

Evans, L., & Fischer, R. (1999). Yield potential: its definition, measurement, and significance. *Crop Science, 39*(6), 1544-1551.

Fan, S., Mogues, T., & Benin, S. (2009). *Setting priorities for public spending for agricultural and rural development in Africa*. (IFPRI Policy Brief No. 12). Washington DC: International Food Policy Research Institute.

FAO. (2012). Statistical Yearbook 2013: world food and agriculture. Rome: Food and Agriculture Organziation.

Färe, R., Grosskopf, S., Norris, M., & Zhang, Z. (1994). Productivity growth, technical progress, and efficiency change in industrialized countries. *American Economic Review, 84*(1), 66-83.

Färe, R., Grosskopf, S., & Pasurka Jr, C. A. (2001). Accounting for air pollution emissions in measures of state manufacturing productivity growth. *Journal of Regional Science, 41*(3), 381-409.

Färe, R., Grosskopf, S., & Sickles, R. (2007). Productivity of US airlines after deregulation. *Journal of Transport Economics and Policy*, *41(1)*, 93-112.

Fernández, C., Ley, E., & Steel, M. F. J. (2001a). Benchmark priors for bayesian model averaging. *Journal of Econometrics, 100*(2), 381-427.

Fernández, C., Ley, E., & Steel, M. F. J. (2001b). Model uncertainty in cross-country growth regressions. *Journal of Applied Econometrics, 16*(5), 563-576.

Fleming, E., & Lummani, J. (2001). *Analysis of the technical efficiency of cocoa smallholders in the Gazelle Peninsula, East New Britain Province* (Occasional Paper No. 7). Armidale, Australia: Centre for Economic Policy Analysis, University of New England.

Foster, A. D., & Rosenzweig, M. R. (1995). Learning by doing and learning from others: Human capital and technical change in agriculture. *Journal of Political Economy, 103(6)*, 1176-1209.

Fowler Jr, F. J. (2013). *Survey research methods* (5th Eds). California: Sage publications.

Fox, M. P., Rosen, S., MacLeod, W. B., Wasunna, M., Bii, M., Foglia, G., & Simon, J. L. (2004). The impact of HIV/AIDS on labour productivity in Kenya. *Tropical Medicine & International Health, 9*(3), 318-324.

Fu, W.-G., Sun, S., & Zhou, Z.-Y. (2011). Technical efficiency of food processing in China: the case of flour and rice processing. *China Agricultural Economic Review, 3*(3), 321-334.

Fuglie, K., & Rada, N. (2013). *Resources, policies, and agricultural productivity in Sub-Saharan Africa.*: The United States Department of Agriculture. Washington DC

Fuglie, K. O. (2010). Total factor productivity in the global agricultural economy: evidence from FAO data. In Alston, J.M., Babcock, B.A & Pardey, P. G. (Eds). *The shifting patterns of agricultural production and productivity worldwide*. (CARD Books No. 2, pp. 63-91). Washington DC: United States Department of Agriculture.

Fuglie, K. O., & Rada, N. E. (2012). Constraints to raising agricultural productivity in Sub-Saharan Africa. In Fuglie, K. O., Wang, S. L., & Ball, V. E. (Eds.). *Productivity Growth in Agriculture: an international perspective*, (pp 237-272). London: Centre for Agriculture and Biosciences International (CABI).

Fukuyama, H., & Weber, W. L. (2010). A slacks-based inefficiency measure for a two-stage system with bad outputs. *Omega*, *38*(5), 398-409.

Fukuyama, H., Weber, W. L., & Xia, Y. (2015). Time substitution and network effects with an application to nanobiotechnology policy for US universities. *Omega, 60*, 34-44.

Fulginiti, L. E., & Perrin, R. K. (1997). LDC agriculture: non-parametric malmquist productivity indexes. *Journal of Development Economics, 53*(2), 373-390.

Fulginiti, L. E., & Perrin, R. K. (1998). Agricultural productivity in developing countries. *Agricultural Economics, 19*(1–2), 45-51.

Fulginiti, L. E., Perrin, R. K., & Yu, B. (2004). Institutions and agricultural productivity in Sub-Saharan Africa. *Agricultural Economics, 31*(2-3), 169-180.

Gabre-Madhin, E. Z., & Haggblade, S. (2004). Successes in African agriculture: results of an expert survey. *World Development, 32*(5), 745-766.

Gebregziabher, G., Namara, R. E., & Holden, S. (2012). Technical efficiency of irrigated and rain-fed smallholder agriculture in Tigray, Ethiopia: a comparative stochastic frontier production function analysis. *Quarterly Journal of International Agriculture, 51*(3), 203-226.

Gerber, P.J., Steinfeld, H., Henderson, B., Mottet, A., Opio, C., Dijkman, J., Falcucci, A., & Tempio, G. (2013). *Tackling climate change through livestock: a global assessment of emissions and mitigation opportunities*. Rome. Food and Agriculture Organization of the United Nations.

Gitau, R., Mburu, S., Mathenge, M. K., & Smale, M. (2011). *Trade and agricultural competitiveness for growth, food security and poverty reduction: a case of wheat and rice production in Kenya.* (Working paper No. 45). Nairobi, Kenya: Tegemeo Institute of Agricultural Policy and Development.

Glopolis (2013). *Food Security and Agricultural Trade in Kenya: The impact of the economic partnership agreement on food security of poor kenyans.* Czech Republic: Prague Global Policy Institute - Glopolis.

Göbel, C., & Zwick, T. (2012). Age and productivity: sector differences. *De Economist, 160*(1), 35-57.

Gold, A. J., & Sims, J. T. (2005). Eutrophication. In Hillel, D., & Hatfield, J. L. (Eds.). *Encyclopedia of soils in the environment* (pp. 486-494). Amsterdam: Elsevier.

Gollin, D., Parente, S., & Rogerson, R. (2002). The role of agriculture in development. *American Economic Review, 92(*2*)*, 160-164.

Goyal, S., Jogdand, S., & Agrawal, A. (2014). Energy use pattern in rice milling industries - a critical appraisal. *Journal of Food Science and Technology, 51*(11), 2907-2916.

Grifell-Tatjé, E., & Lovell, C. A. K. (1995). A note on the Malmquist productivity index. *Economics Letters, 47*(2), 169-175.

Guanziroli, C. E., & Frischtak, C. (2011). *Integrated productivity programme for agriculture in Mozambique. (*Working paper No. F-36002-MOZ-1). London: The International Growth Centre, London School of Economic and Political Science.

Gunatilake, H., & Gopalakrishnan, C. (2010). Technical efficiency of sawmilling and the conservation of natural forests: evidence from Sri Lanka. *Journal of Natural Resources Policy Research, 2*(2), 149-169.

Hayami, Y., & Ruttan, V. W. (1970). Agricultural productivity differences among countries. *American Economic Review, 60(*5*)*, 895-911.

Hayami, Y., & Ruttan, V. W. (1985). *Agricultural development: an international perspective* (Revised Ed). Baltimore, MD/London: The Johns Hopkins Press.

Helfand, S. M., & Levine, E. S. (2004). Farm size and the determinants of productive efficiency in the Brazilian Center-West. *Agricultural Economics, 31*(2-3), 241-249.

Henderson, B. B., & Kingwell, R. S. (2005). Rainfall and farm efficiency measurement for broadacre agriculture in South-Western Australia. *Australasian Agribusiness Review*, *13* (14).

Heriqbaldi, U., Purwono, R., Haryanto, T., & Primanthi, M. R. (2014). An analysis of technical efficiency of rice production in Indonesia. *Asian Social Science, 11*(3), 91-102.

Hicks, J. R. (1961). The measurement of capital in relation to the measurement of other economic aggregates. In Lutz, F.A. & Hague, D.C. (eds), *The theory of capital*, 18-31. London: Palgrave Macmillan.

Hickman, J. E., Havlikova, M., Kroeze, C., & Palm, C. A. (2011). Current and future nitrous oxide emissions from African agriculture. *Current Opinion in Environmental Sustainability*, *3*(5), 370-378.

Hoang, V.-N., & Coelli, T. (2011). Measurement of agricultural total factor productivity growth incorporating environmental factors: a nutrients balance approach. *Journal of Environmental Economics and Management, 62*(3), 462-474.

Hodges, R. J., Buzby, J. C., & Bennett, B. (2011). Postharvest losses and waste in developed and less developed countries: opportunities to improve resource use. *Journal of Agricultural Science, 149*(S1), 37-45.

Hoff, A. (2007). Second stage DEA: Comparison of approaches for modelling the DEA score. *European Journal of Operational Research*, *181*(1), 425-435.

HoAfricain, M., Kamil, A., Masron, T., & Baten, M. A. (2013). Impact of environmental factors on efficiency of rice production in Bangladesh. *Journal of Applied Sciences, 13*(4), 564-571.

Hsiao, C. (2007). Panel data analysis - advantages and challenges. *TEST, 16*(1), 1-22.

Ibitoye, S., Idoko, D., & Shaibu, U. (2014). Economic assessment of rice processing in BaAfrica local government area of Kogi state, Nigeria. *Asian Journal of Basic and Applied Sciences, 1*(2), 8-17.

IFPRI. (2010). *2009 Annual report*. Washington, DC: International Food Policy Research Institute.

IMF (2000). *Gambia – The selected issues. Staff country reports*. Washington DC: International Monetary Fund Publications.

IPCC. (2007). *Climate Change 2007: synthesis report*. (Contribution of working groups I, II and III to the fourth assessment report of the Intergovernmental Panel on Climate Change). Geneva, Switzerland: Intergovernmental Panel on Climate Change.

Iraizoz, B., Rapun, M., & Zabaleta, I. (2003). Assessing the technical efficiency of horticultural production in Navarra, Spain. *Agricultural Systems, 78*(3), 387-403.

Ironkwe, A., Ewuziem, J., & Ekwe, K. (2014). Gender factors influencing technical efficiency of cassava farmers in Akwa Ibom State, Nigeria. *Journal of Agriculture and Food Sciences, 11*(2), 26-36.

Irz, X., Lin, L., Thirtle, C., & Wiggins, S. (2001). Agricultural productivity growth and poverty alleviation. *Development Policy Review, 19*(4), 449-466.

Islam, N., Xayavong, V., & Kingwell, R. (2014). Broadacre farm productivity and profitability in south ‐ western Australia. *Australian Journal of Agricultural and Resource Economics*, *58*(2), 147-170.

Jefferson, P. N., & O’Connell, S. A. (2004). Rainfall shocks and economic performance in four African countries. *Worldwide Database on rainfall and drought severity, http://www. acad. swarthmore. edu/rain-econ/Framesets/HomePage. htm*.

Jiang, N., & Sharp, B. (2015). Technical efficiency and technological gap of New Zealand dairy farms: a stochastic meta-frontier model. *Journal of Productivity Analysis*, *44*(1), 39-49.

Jin, S., Ma, H., Huang, J., Hu, R., & Rozelle, S. (2010). Productivity, efficiency and technical change: measuring the performance of China’s transforming agriculture. *Journal of Productivity Analysis, 33*(3), 191-207.

Jones, D. C., Kalmi, P., & Kauhanen, A. (2010). Teams, incentive pay, and productive efficiency: Evidence from a food-processing plant. *Industrial & Labor Relations Review, 63*(4), 606-626.

Kader, A. A. (2004). Increasing food availability by reducing postharvest losses of fresh produce. In *V International Postharvest Symposium. Acta Horticulturae, 682,* 2169-2176.

Kadiri, F., Eze, C., Orebiyi, J., Lemchi, J., Ohajianya, D., & Nwaiwu, I. (2014). Technical Efficiency in paddy rice production in Niger delta region of Nigeria. *Global Journal of Agricultural Research, 2*(2), 33-43.

Kalirajan, K., & Shand, R. (1985). Types of education and agricultural productivity: a quantitative analysis of Tamil Nadu rice farming. *Journal of Development Studies, 21*(2), 232-243.

Kannan, E. (2013). Analysis of total factor productivity growth in Karnataka agriculture. *Productivity, 54*(2), 151-163.

Kapelko, M., & Lansink, A. (2013). Technical Efficiency of the Spanish Dairy Processing Industry: Do Size and Exporting Matter? In Mendes, A. B., Soares da Silva, E. L. D. G. & Santos A. J. M. (Eds.), *Efficiency Measures in the Agricultural Sector* (pp. 93-106). Netherlands: Springer Science & Business Media.

Kapelko, M., Lansink, A. O., & Stefanou, S. E. (2015). Effect of food regulation on the Spanish food processing industry: a dynamic productivity analysis. *PloS One, 10*(6), 1-16.

Kawagoe, T., & Hayami, Y. (1983). The production structure of world agriculture: an intercountry cross ‐ section analysis. *The Developing Economies, 21*(3), 189-206.

Kherallah, M., Delgado, C., Gabre-Madhin, E., Minot, E., & Johnson, M. (Eds.). (2002). *Reforming agricultural markets in Africa*. Baltimore: Johns Hopkins University Press.

Khai, H. V., & Yabe, M. (2011). Technical efficiency analysis of rice production in Vietnam. *Journal of ISSAAS*, *17*(1), 135-146.

Kilic, O., Ceyhan, V., & Alkan, I. (2009). Determinants of economic efficiency: a case study of hazelnut (corylus avellana) farms in Samsun Province, Turkey. *New Zealand Journal of Crop and Horticultural Science, 37*(3), 263-270.

Kimuyu, P. (2005). *Productivity performance in developing countries.* Nairobi, Kenya: United Nations Industrial Development Organization,.

Kiplagat, J. K., Wang, R. Z., & Li, T. X. (2011). Renewable energy in Kenya: resource potential and status of exploitation. *Renewable and Sustainable Energy Reviews, 15*(6), 2960-2973.

Kitinoja, L., & AlHassan, H. (2010). Identification of appropriate postharvest technologies for small-scale horticultural farmers and marketers in Sub-Saharan Africa and South Asia-Part 1. Postharvest losses and quality assessments. In *XXVIII International Horticultural Congress on Science and Horticulture for People (IHC2010): International Symposium on postharvest technology in the global market*, *Acta Horticulturae 934,* 31-40.

Kumar, S. (2006). Environmentally sensitive productivity growth: a global analysis using Malmquist–Luenberger index. *Ecological Economics, 56*(2), 280-293.

Kumar, S., & Managi, S. (2010). Environment and productivities in developed and developing countries: The case of carbon dioxide and sulfur dioxide. *Journal of Environmental Management, 91*(7), 1580-1592.

Kumbhakar, S. C., & Lovell, C. K. (2003). *Stochastic frontier analysis*. Cambridge: Cambridge University Press.

Kuria, J., Ommeh, H., Kabuage, L., Mbogo, S., & Mutero, C. (2003). Technical Efficiency of rice producers in Mwea Irrigation Scheme. *Proceedings of the African Crop Science Conference* (Vol. 6, pp. 668-673). Nairobi, Kenya.

Lall, S., & Pietrobelli, C. (2002). *Failing to compete: technology development and technology systems in Africa.* Cheltenham: Edward Elgar Publishing Ltd.

Latruffe, L., Balcombe, K., Davidova, S., & Zawalinska, K. (2004). Determinants of technical efficiency of crop and livestock farms in Poland. *Applied Economics, 36*(12), 1255-1263.

Lau, L. J., & Yotopoulos, P. A. (1989). The meta-production function approach to technological change in world agriculture. *Journal of Development Economics, 31*(2), 241-269.

Lee, B. L., & Worthington, A. C. (2015). A network DEA quantity and quality-orientated production model: an application to Australian university research services. *Omega*, *60*, 26-33.

Lee, B. L., Wilson, C., & Pasurka Jr, C. A. (2015). The good, the bad, and the efficient: productivity, efficiency and technical change in the airline industry, 2004–11. *Journal of Transport Economics and Policy*, *49*(2), 338-354.

Lin, H. T. (2010). Personnel selection using analytic network process and fuzzy data envelopment analysis approaches. *Computers & Industrial Engineering*, *59*(4), 937-944.

Lohr, L., & Park, T. A. (2006). Technical efficiency of US organic farmers: The complementary roles of soil management techniques and farm experience. *Agricultural and Resource Economics Review, 35*(2), 327-338.

Maclean, J. L., Dawe, D.C., Hardy, B., & Hettel G.P. (2002). *Rice almanac: source book for the most important economic activity on earth* (3rd Ed). Wallingford, UK: CABI Publishing.

Madigan, D., & Raftery, A. E. (1994). Model selection and accounting for model uncertainty in graphical models using Occam's window. *Journal of the American Statistical Association, 89*(428), 1535-1546.

Mahmood, N., Ahmad, B., HaAfrican, S., & Bakhsh, K. (2012). Impact of temperature and precipitation on rice productivity in rice-wheat cropping system of Punjab province. *Journal of Animal and Plant Sciences, 22*(4), 993-997.

Mallawaarachchi, T., Walcott, J., Hughes, N., Gooday, P., Georgeson, L., & Foster, A. (2009). Promoting productivity in the agriculture and food sector value chain: issues for R&D investment. *ABARE and BRS report to the Rural R&D Council, Canberra, December*.

Mati, B. M., Wanjogu, R., Odongo, B., & Home, P. G. (2011). Introduction of the System of Rice Intensification in Kenya: experiences from Mwea Irrigation Scheme. *Paddy and Water Environment, 9*(1), 145-154.

Maxime, D., Marcotte, M., & Arcand, Y. (2006). Development of eco-efficiency indicators for the Canadian food and beverage industry. *Journal of Cleaner Production, 14*(6), 636-648.

Mbabazi, J., Bah, M. E.-h. M., & Verdier-Chouchane, A. (2015). *Transforming Africa's agriculture to improve competitiveness. (The Africa competitiveness report 2015,* pp 37-52). Côte d'Ivoire: African Development bank..

McDonald, J. (2009). Using least squares and tobit in second stage DEA efficiency analyses. *European Journal of Operational Research*, *197*(2), 792-798.

Mertz, O., Halsnæs, K., Olesen, J. E., & Rasmussen, K. (2009). Adaptation to climate change in developing countries. *Environmental Management, 43*(5), 743-752.

Messer, E., Cohen, M. J., & Marchione, T. (2001). *Conflict: A cause and effect of hunger. (Special reports 1*(7), 1-16). Washington DC: Environmental change and security program, Wilson Center..

Minten, B., & Barrett, C. B. (2008). Agricultural Technology, Productivity, and Poverty in Madagascar. *World Development, 36*(5), 797-822.

Mirhedayatian, S. M., Azadi, M., & Saen, R. F. (2014). A novel network data envelopment analysis model for evaluating green supply chain management. *International Journal of Production Economics*, *147*, 544-554.

Misselhorn, A., Aggarwal, P., Ericksen, P., Gregory, P., Horn-Phathanothai, L., Ingram, J., & Wiebe, K. (2012). A vision for attaining food security. *Current Opinion in Environmental Sustainability, 4*(1), 7-17.

Mitchell, T., Carter, T., Jones, P., Hulme, M., & New, M. (2004). A comprehensive set of climate scenarios for Europe and the globe: the observed record (1900-2000) and 16 scenarios (2000-2100). Norwich, UK: University of East Anglia.

Mohanty, S. (2013). Trends in global rice consumption. *Rice Today, 12*(1), 44-45.

Moorsteen, R. H. (1961). On measuring productive potential and relative efficiency. *Quarterly Journal of Economics*, 451-467.

Mueller, B., & Mueller, C. (2016). The political economy of the Brazilian model of agricultural development: institutions versus sectoral policy. *Quarterly Review of Economics and Finance*, *62*, 12-20.

Mugera, A. W., & Featherstone, A. M. (2008). Backyard Hog Production Efficiency: Evidence from the Philippines. *Asian Economic Journal, 22*(3), 267-287.

Mujeri, M. K., Shahana, S., Chowdhury, T. T., & Haider, K. T. (2012). Improving the effectiveness, efficiency and sustainability of fertilizer use in South Asia (*Research policy paper No.8)*. New Delhi: Global Development Network.

Munang, R., Thiaw, I., Alverson, K., Goumandakoye, M., Mebratu, D. & Liu, J. (2013). Using ecosystem-based adaptation actions to tackle food insecurity. *Environment: Science and Policy for Sustainable Development. 55*(1), 29-35.

Mushtaq, S., Maraseni, T. N., Maroulis, J., & Hafeez, M. (2009). Energy and water tradeoffs in enhancing food security: A selective international assessment. *Energy Policy, 37*(9), 3635-3644.

Mustapha, N. H. N., Hashim, N. M. H., & Yacob, R. (2013). Technical components of total factor productivity growth in Malaysian manufacturing industry. *Applied Mathematics, 4*(9), 1251-1259.

Nagothu, U. S. (2014). *Food security and development: country case studies*. New York, NY: Routledge.

Nakano, M., & Managi, S. (2010). Productivity analysis with CO_2 emissions in Japan. *Pacific Economic Review, 15*(5), 708-718.

Neuman, W. L. (2009). *Social research methods: qualitative and quantitative approaches*. Boston, MA: Pearson/Allyn & Bacon

Nin-Pratt, A., & Yu, B. (2012). Agricultural productivity and policy changes in Sub-Saharan Africa. In Fuglie, K. O., Wang, S. L. & Ball V. E. (Eds.). *Productivity growth in agriculture: an international perspective* (pp. 237-272). London: Centre for Agriculture and Biosciences International.

Nin, A., Arndt, C., Hertel, T. W., & Preckel, P. V. (2003). Bridging the gap between Partial and Total Factor Productivity measures using directional distance functions. *American Journal of Agricultural Economics, 85*(4), 928-942.

Nin, A., Arndt, C., & Preckel, P. V. (2003). Is agricultural productivity in developing countries really shrinking? New evidence using a modified nonparametric approach. *Journal of Development Economics, 71*(2), 395-415.

Nin Pratt, A., & Yu, B. (2008). *An updated look at the recovery of agricultural productivity in sub-Saharan Africa* (Discussion paper No. 787). Washington DC: International Food Policy Research Institute.

Nkamleu, G. B. (2004). Productivity growth, technical progress and efficiency change in African agriculture. *African Development Review, 16*(1), 203-222.

Nkamleu, G. B., Sylla, K., & Zonon, A. (2008). What accounts for growth in African agriculture. *American Journal of Agricultural and Biological Sciences, 3*(1), 379-388.

Nyamai, M., Mati, M., Home, P., Odongo, B., Wanjogu, R., & Thuranira, E. (2012). Improving land and water productivity in basin rice cultivation in Kenya through system of rice intensification (SRI). *Agricultural Engineering International: CIGR Journal, 14*(2), 1-9.

Nyariki, D. M. (2011). Farm size, modern technology adoption and efficiency of small holdings in developing countries: evidence from Kenya. *Journal of Developing Areas*, *45*(1), 35-52.

O’Donnell, C. J. (2010). Measuring and decomposing agricultural productivity and profitability change. *Australian Journal of Agricultural and Resource Economics, 54*(4), 527-560.

O'Donnell, C. J. (2011a). *The sources of productivity change in the manufacturing sectors of the US economy* (CEPA working paper No. 072011). Centre for Efficiency and Productivity Analysis, University of Queensland.

O’Donnell, C. J. (2011b). *DPIN 3.0: A program for decomposing productivity index numbers.* Queensland, Australia: Centre for Efficiency and Productivity Analysis, University of Queensland.

O’Donnell, C. J. (2012a). An aggregate quantity framework for measuring and decomposing productivity change. *Journal of Productivity Analysis, 38*(3), 255-272.

O'Donnell, C. J. (2012b). Nonparametric estimates of the components of productivity and profitability change in U.S. agriculture. *American Journal of Agricultural Economics, 94*(4), 873-890.

O'Donnell, C. J., Rao, D. P., & Battese, G. E. (2008). Metafrontier frameworks for the study of firm-level efficiencies and technology ratios. *Empirical Economics, 34*(2), 231-255.

O'Donnell, C. J. (2014). Econometric estimation of distance functions and associated measures of productivity and efficiency change. *Journal of Productivity Analysis*, *41*(2), 187-200.

Odhiambo, W., Nyangito, H. O., & Nzuma, J. (2004). *Sources and determinants of agricultural growth and productivity in Kenya*: Kenya Institute for Public Policy Research and Analysis. Kenya.

Oehler, V. G., Yeung, K. Y., Choi, Y. E., Bumgarner, R. E., Raftery, A. E., & Radich, J. P. (2009). The derivation of diagnostic markers of chronic myeloid leukemia progression from microarray data. *Blood, 114*(15), 3292-3298.

Ogundari, K. (2010). Estimating and analysing cost-efficiency of sawmill industries in Nigeria: a stochastic frontier approach. *China Agricultural Economic Review, 2*(4), 420-432.

Oh, D.-h. (2010a). A global malmquist-luenberger productivity index. *Journal of Productivity Analysis, 34*(3), 183-197.

Oh, D.-h. (2010b). A metafrontier approach for measuring an environmentally sensitive productivity growth index. *Energy Economics, 32*(1), 146-157.

Oh, D.-h., & Heshmati, A. (2010). A sequential Malmquist–Luenberger productivity index: Environmentally sensitive productivity growth considering the progressive nature of technology. *Energy Economics, 32*(6), 1345-1355.

Okigbo, B. N. (1982). Agriculture and food production in tropical Africa. *Paper presented at the USAID/ADC seminar on "improving effectiveness of food aid in Africa.* 23rd -26th August, Abidjan, Ivory Coast.

Oladeebo, J. O. (2012). Technical Efficiency and Rural Poverty among Farmers in Nigeria: A Gender Perspective. *Global Journal of Science Frontier Research, 12*(8), 1-8.

Omondi, S. O., & Shikuku, K. M. (2013). An analysis of technical efficiency of rice farmers in ahero irrigation scheme, Kenya. *Journal of Economics and Sustainable Development, 4*(10), 9-16.

Oxfam. (2013). *Growing disruption : climate change, food and the fight against hunger* (Oxfam issue briefing). United Kingdom: Oxfam GB.

Papke, L. E., & Wooldridge, J. M. (1996). Econometric methods for fractional response variables with an application to 401 (k) plan participation rates. *Journal of Applied Econometrics, 11*(6), 619-632.

Parikh, A., & Shah, K. (1994). Measurement of technical efficiency in North-West Frontier Province of Pakistan. *Journal of Agricultural Economics*, *45*(1), 132-138.

Pate, N. T., & Cruz, A. T. (2007). Technical efficiency of Philippine rice-producing region: an econometric approach. *Proceeding of 10th National Convention on Statistics* (pp. 1-2). Phillipines: Phillipine Statistical System.

Pathomsiri, S., Haghani, A., Dresner, M., & Windle, R. J. (2008). Impact of undesirable outputs on the productivity of US airports. *Transportation Research Part E: Logistics and Transportation Review, 44*(2), 235-259.

Patrick, G. F., & Kehrberg, E. W. (1973). Costs and returns of education in five agricultural areas of eastern Brazil. *American Journal of Agricultural Economics*, *55*(2), 145-153.

Pauw, K., & Thurlow, J. (2011). Agricultural growth, poverty and nutrition in Tanzania. *Food Policy, 36*(6), 795-804.

Peyrache, A. (2014). Hicks-Moorsteen versus Malmquist: a connection by means of a radial productivity index. *Journal of Productivity Analysis, 41*(3), 435-442.

Phillip, D., Nkonya, E., Pender, J., & Oni, O. A. (2009). *Constraints to increasing agricultural productivity in Nigeria: A review* (Background paper No. NSSP 006). Abuja, Nigeria: International Food Policy Research Institute.

Picazo-Tadeo, A. J., Reig-Martínez, E., & Hernández-Sancho, F. (2005). Directional distance functions and environmental regulation. *Resource and Energy Economics, 27*(2), 131-142.

Piotti, E., Rigano, M. M., Rodino, D., Rodolfi, M., Castiglione, S., Picco, A. M., & Sala, F. (2005). Genetic Structure of Pyricularia grisea (Cooke) Sacc. Isolates from Italian Paddy Fields. *Journal of Phytopathology, 153*(2), 80-86.

Place, F. (2009). Land Tenure and Agricultural Productivity in Africa: A Comparative Analysis of the Economics Literature and Recent Policy Strategies and Reforms. *World Development, 37*(8), 1326-1336.

Pratt, A. N., & Yu, B. (2008). *An updated look at the recovery of agricultural productivity in Sub-Saharan Africa* (Discussion Paper No. 787). Washington DC: International Food Policy Research Institute.

Raftery, A. E. (1995). Bayesian model selection in social research. *Sociological Methodology, 25*, 111-164.

Rahman, S., & Salim, R. (2013). Six decades of total factor productivity change and sources of growth in Bangladesh agriculture (1948–2008). *Journal of Agricultural Economics, 64*(2), 275-294.

Ramalho, E. A., Ramalho, J. J., & Henriques, P. D. (2010). Fractional regression models for second stage DEA efficiency analyses. *Journal of Productivity Analysis, 34*(3), 239-255.

Rao, D., O'donnell, C. J., & Battese, G. E. (2003). *Metafrontier functions for the study of inter-regional productivity differences*. (CEPA working paper No. 01/2003). Queensland, Australia: School of Economics, University of Queensland.

Rao, D. P., & Coelli, T. (2004). Catch-up and convergence in global agricultural productivity. *Indian Economic Review, 39*(1), 123-148.

Rao, D. S. P. (1993). *Intercountry comparisons of agricultural output and productivity*. (FAO econmic and social development paper No. 112). Department of Econometrics, University of New England, Armidale, Australia.

Ravallion, M., & Datt, G. (1996). How important to India's poor is the sectoral composition of economic growth? *World Bank Economic Review, 10*(1), 1-25.

Ravn, M. O., & Uhlig, H. (2002). On adjusting the Hodrick-Prescott filter for the frequency of observations. *Review of Economics and Statistics, 84*(2), 371-376.

Ray, D. K., Ramankutty, N., Mueller, N. D., West, P. C., & Foley, J. A. (2012). Recent patterns of crop yield growth and stagnation. *Nature communications*, *3*, 1293.

Ray, S. C. (1991). Resource-use efficiency in public schools: a study of Connecticut data. *Management Science*, *37*(12), 1620-1628.

Republic of Kenya-RoK (2007). The Kenya Vision 2030. Ministry of Planning and National Development, Nairobi, Kenya.

Republic of Kenya-RoK (2010a). The Constitution of Kenya, Article 43 (c). Nairobi, Kenya.

Republic of Kenya-RoK. (2010b). *Agricultural Sector Development Strategy 2010-2020.* Nairobi, Kenya: Ministry of Agriculture.

Republic of Kenya-RoK. (2011). *National Food and Nutritional Security Policy.* Nairobi, Kenya: Agricultural Sector Coordination Unit

Rezek, J. P., Campbell, R. C., & Rogers, K. E. (2011). Assessing total factor productivity growth in Sub‐Saharan African agriculture. *Journal of Agricultural Economics*, *62*(2), 357-374.

Sachs, J. D., & Warner, A. M. (1995). *Natural resource abundance and economic growth (Working Paper No. 5398)*. National Bureau of Economic Research, Cambridge

Sadoulet, E., & De Janvry, A. (1995). *Quantitative development policy analysis*: Baltimore, MD/London: The Johns Hopkins Press.

Salami, A., Kamara, A. B., & Brixiova, Z. (2010). *Smallholder agriculture in East Africa: trends, constraints and opportunities*. (Working paper No. 105). African Development Bank. Tunis, Tunisia.

Sarker, M. A. R., Alam, K., & Gow, J. (2012). Exploring the relationship between climate change and rice yield in Bangladesh: An analysis of time series data. *Agricultural Systems, 112*, 11-16.

Sejian, V., & Naqvi, S. (2012). *Livestock and climate change: Mitigation strategies to reduce methane production*. Division of Physiology and Biochemistry, Central Sheep and Wool Research Institute, Avikanagar, India.

Sekhon, M., Mahal, A. K., Kaur, M., & Sidhu, M. (2010). Technical efficiency in crop production: A region-wise analysis. *Agricultural Economics Research Review, 23*(2), 367-374.

Sexton, T. R., Sleeper, S., & Taggart, R. E. (1994). Improving pupil transportation in North Carolina. *Interfaces*, *24*(1), 87-103.

Shekania, B., & Mwangi, W. (1996). *Adoption of recommended maize technologies in Mbeya Region of the southern highlands of Tanzania*. Addis Baba, Ethiopia: International Maize and Wheat Improvement Center/the United Republic of Tanzania.

Shephard R.W (1953). *Cost and production functions*. Princeton, New Jersey: Princeton University Press.

Shephard R.W (1970). The theory of cost and production functions. Princeton, New Jersey: Princeton University Press.

Shetto, R., & Lyimo, M. (2001). *Conservation agriculture in Tanzania*. *Paper presented at LAMP Planning Workshop on Conservation Tillage, Babati, 19-21 December 2001*. Dar es Salaam, Tanzania.

Short, C., Mulinge, W., & Witwer, M. (2012). *Analysis of incentives and disincentives for rice in Kenya* (Technical notes series). Rome: Monitoring African Food and Agricultural Policies project, Food and Agriculture Organization.

Sibiko, K. W., Owuor, G., Birachi, E., Gido, E., Ayuya, O., & Mwangi, J. (2013). Analysis of determinants of productivity and technical efficiency among smallholder common bean farmers in eastern Uganda. *Current Research Journal of Economic Theory, 5*(3), 44-55.

Simar, L., & Wilson, P. W. (2007). Estimation and inference in two-stage, semi-parametric models of production processes. *Journal of Econometrics*, *136*(1), 31-64.

Sivakumar, M. V. K., Das, H. P., & Brunini, O. (2005). Impacts of present and future climate variability and change on agriculture and forestry in the arid and semi-arid tropics. *Climatic Change, 70*(1-2), 31-72.

Skevas, T., Lansink, A. O., & Stefanou, S. E. (2012). Measuring technical efficiency in the presence of pesticide spillovers and production uncertainty: the case of Dutch arable farms. *European Journal of Operational Research, 223*(2), 550-559.

Solow, R. M. (1957). Technical change and the aggregate production function. *Review of Economics and Statistics, 39*(3), 312-320.

Spielman, D. J., & Pandya-Lorch, R. (2010). *Proven successes in agricultural development: a technical compendium to millions fed*. Washington, DC: International Food Policy Research Institute.

Stanton, K. R. (2002). Trends in relationship lending and factors affecting relationship lending efficiency. *Journal of Banking & Finance*, *26*(1), 127-152.

Subramaniam, S. K. A. L., Husin, S. H. B., Yusop, Y. B., & Hamidon, A. H. B. (2009). Machine efficiency and man power utilization on production lines. *Proceedings of the 8th WSEAS International conference on electronics, hardware, wireless and optical communications,* February 21 - 23. Stevens Point, Wisconsin: World Scientific and Engineering Academy and Society.

Sufian, F. (2011). Banks total factor productivity change in a developing economy: Does ownership and origins matter? *Journal of Asian Economics, 22*(1), 84-98.

Takeshima, H. (2014). *Importance of rice research and development in rice seed policies: insights from Nigeria* (Discussion Paper No. 01343). Washington, DC: International Food Policy Research Institute.

Thanh Nguyen, T., Hoang, V.-N., & Seo, B. (2012). Cost and environmental efficiency of rice farms in South Korea. *Journal of Agricultural Economics, 43*(4), 369-378.

Thirtle, C., & Bottomley, P. (1992). Total factor productivity in UK agriculture, 1967-90. *Journal of Agricultural Economics, 43*(3), 381-400.

Thirtle, C., Piesse, J., Lusigi, A., & Suhariyanto, K. (2003). Multi-factor agricultural productivity, efficiency and convergence in Botswana, 1981–1996. *Journal of Development Economics, 71*(2), 605-624.

Thirtle, C., von Bach, H. S., & van Zyl, J. (1993). Total factor productivity in South African agriculture, 1947-91. *Development Southern Africa, 10*(3), 301-318.

Tian, W., & Wan, G. H. (2000). Technical efficiency and its determinants in China's grain production. *Journal of Productivity Analysis*, *13*(2), 159-174.

Timmer, M. P., O'Mahony, M., & Van Ark, B. (2007). Growth and productivity accounts from EU KLEMS: an overview. *National Institute Economic Review, 200*(1), 64-78.

Timmer, P. C. (2010). *Food Security in Asia and the Changing Role of Rice* (Occasional Paper No. 4). Sidney, Australia: Asia foundation.

Tone, K., & Tsutsui, M. (2009). Network DEA: a slacks-based measure approach. *European Journal of Operational Research, 197*(1), 243-252.

Tortosa-Ausina, E., Grifell-Tatjé, E., Armero, C., & Conesa, D. (2008). Sensitivity analysis of efficiency and malmquist productivity indices: an application to Spanish savings banks. *European Journal of Operational Research, 184*(3), 1062-1084.

Tozer, P. R., & Villano, R. (2013). Decomposing productivity and efficiency among Western Australian grain producers. *Journal of Agricultural and Resource Economics, 38*(3), 312-326.

Tran, N. A., Shively, G., & Preckel, P. (2010). A new method for detecting outliers in Data Envelopment Analysis. *Applied Economics Letters, 17*(4), 313-316.

Trueblood, M. A., & Coggins, J. (2003). Intercountry agricultural efficiency and productivity: A Malmquist index approach. World Bank, Washington, DC.

Tubiello, F., Salvatore, M., & Cóndor Golec, R. (2014). *Agriculture, forestry and other land use emissions by sources and removals by sinks*. (FAO Statistics Division working paper No. ESS/14-02). Rome: Food and Agriculture Organization.

Turner, N. C. (2004). Agronomic options for improving rainfall-use efficiency of crops in dryland farming systems. *Journal of Experimental Botany, 55*(407), 2413-2425.

UNCHR (2016). Kenya comprehensive refugee programme 2016: Programming for solutions. Nairobi, Kenya: United Nations High Commissioner for Refugees.

UNDP. (2013). Human Development reports. United Nations Development Programme. http://hdr.undp.org/en/content/mean-years-schooling-adults-years.

UNEP. (2013) *Ecosystem-based approaches key to tackling challenge of African food security amidst changing climate*. Nairobi: United Nations Environmental Programme.

United Republic of Tanzania-URT. (2001.). *Agricultural sector development strategy.* Dar es Salaam: United Republic of Tanzania

United Republic of Tanzania-URT. (2003). *Agricultural sector development programme: framework and process document* (Final draft report). Dar es Salaam: United Republic of Tanzania.

Van Biesebroeck, J. (2007). Robustness of productivity estimates. *Journal of Industrial Economics, 55*(3), 529-569.

Vaz, C. B., Camanho, A. S., & Guimarães, R. C. (2010). The assessment of retailing efficiency using network data envelopment analysis. *Annals of Operations Research*, *173*(1), 5-24.

Villano, R., & Mehrabi Boshrabadi, H. (2010). When is metafrontier analysis appropriate? An example of varietal differences in Pistachio production in Iran. *Journal of Agricultural Science and Technology, 4*(12), 379-389.

Villano, R., & Fleming, E. (2006). Technical inefficiency and production risk in rice farming: evidence from Central Luzon Philippines. *Asian Economic Journal*, *20*(1), 29-46.

Von Braun, J., Hill, R. E., & Pandya-Lorch, R. (2009). *The poorest and hungry: Assessments, analyses and actions: an IFPRI 2020 Book*. Washington DC: International Food Policy Research Institute.

Von Braun, J., Teklu, T., & Webb, P. (1999). *Famine in Africa: causes, responses, and prevention.* Washington DC: International Food Policy Research Institute.

Von Grebmer, K., Bernstein, J., de Waal, A., Prasai, N., Yin, S., & Yohannes, Y. (2015). *2015 Global hunger index: armed conflict and the challenge of hunger*. Washington DC: International Food Policy Research Institute.

Wadud, M. A. (2003). Technical, allocative, and economic efficiency of farms in Bangladesh: a stochastic frontier and DEA approach. *Journal of Developing Areas, 37*(1), 109-126.

Wei, X., Declan, C., Erda, L., Yinlong, X., Hui, J., Jinhe, J., Ian, H., & Yan, L. (2009). Future cereal production in China: the interaction of climate change, water availability and socio-economic scenarios. *Global Environmental Change, 19*(1), 34-44.

Wiebe, K., Soule, M. J., Narrod, C., & Breneman, V. E. (2003). Resource quality and agricultural productivity: A multi-country comparison. In Wiebe,

K. (Eds.). *Land quality, agricultural productivity and food security: biophysical processes and economic choices at local, regional and global levels* (pp. 147-165). Northampton: Edward Elgar Publishing Ltd.

Welch, E., & Barnum, D. (2009). Joint environmental and cost-efficiency analysis of electricity generation. *Ecological Economics, 68*(8–9), 2336-2343.

Farmar-Bowers, Q., Higgins, V. & Millar, J. (2013). *Food Security in Australia*. NewYork, NY: Springer Science and Business Media.

Wilson, P., Hadley, D., Ramsden, S., & Kaltsas, I. (1998). Measuring and explaining technical efficiency in UK potato production. *Journal of Agricultural Economics, 49*(3), 294-305.

Wintle, B. A., McCarthy, M. A., Volinsky, C. T., & Kavanagh, R. P. (2003). The use of Bayesian model averaging to better represent uncertainty in ecological models. *Conservation Biology, 17*(6), 1579-1590.

Wolde-Rufael, Y. (2005). Energy demand and economic growth: The African experience. *Journal of Policy Modeling, 27*(8), 891-903.

Worldbank. (2006). *Mozambique agricultural development strategy: stimulating smallholder agricultural growth*: Washington, DC: The World Bank.

WorldBank. (2013). *Poverty overview*.Washington, DC: The World Bank. http://www.worldbank.org/en/topic/poverty/overview

Worldbank. (2014). World Development Indicators | Data - The World Bank. http://databank.worldbank.org/data/reports.aspx?source=world-development-indicators#

Worldbank. (2014b). 2005 PPP conversion factor, GDP (LCU per international $)

http://data.worldbank.org/indicator/PA.NUS.PPP.05?page=2

Wu, S., Walker, D., Devadoss, S., & Lu, Y. c. (2001). Productivity growth and its components in Chinese agriculture after reforms. *Review of Development Economics, 5*(3), 375-391.

Yao, R. T., & Shively, G. E. (2007). Technical change and productive efficiency: irrigated rice in the Philippines. *Asian Economic Journal*, *21*(2), 155-168.

Yeung, K. Y., Bumgarner, R. E., & Raftery, A. E. (2005). Bayesian model averaging: development of an improved multi-class, gene selection and classification tool for microarray data. *Bioinformatics, 21*(10), 2394-2402.

Yörük, B. K., & Zaim, O. (2005). Productivity growth in OECD countries: a comparison with malmquist indices. *Journal of Comparative Economics, 33*(2), 401-420.

Yu, M.-M., Hsu, S.-H., Chang, C.-C., & Lee, D.-H. (2008). Productivity growth of Taiwan's major domestic airports in the presence of aircraft noise. *Transportation Research Part E: Logistics and Transportation Review, 44*(3), 543-554.

Yu, M. M., & Lin, E. T. (2008). Efficiency and effectiveness in railway performance using a multi-activity network DEA model. *Omega*, *36*(6), 1005-1017

Zeller, M., Diagne, A., & Mataya, C. (1998). Market access by smallholder farmers in Malawi: implications for technology adoption, agricultural productivity and crop income. *Agricultural Economics, 19*(1–2), 219-229.

Zhang, C., Liu, H., Bressers, H. T. A., & Buchanan, K. S. (2011). Productivity growth and environmental regulations - accounting for undesirable outputs: analysis of China's thirty provincial regions using the malmquist–luenberger index. *Ecological Economics, 70*(12), 2369-2379.

Zhang, T. (2008). Environmental performance in China's agricultural sector: a case study in corn production. *Applied Economics Letters, 15*(8), 641-645. .

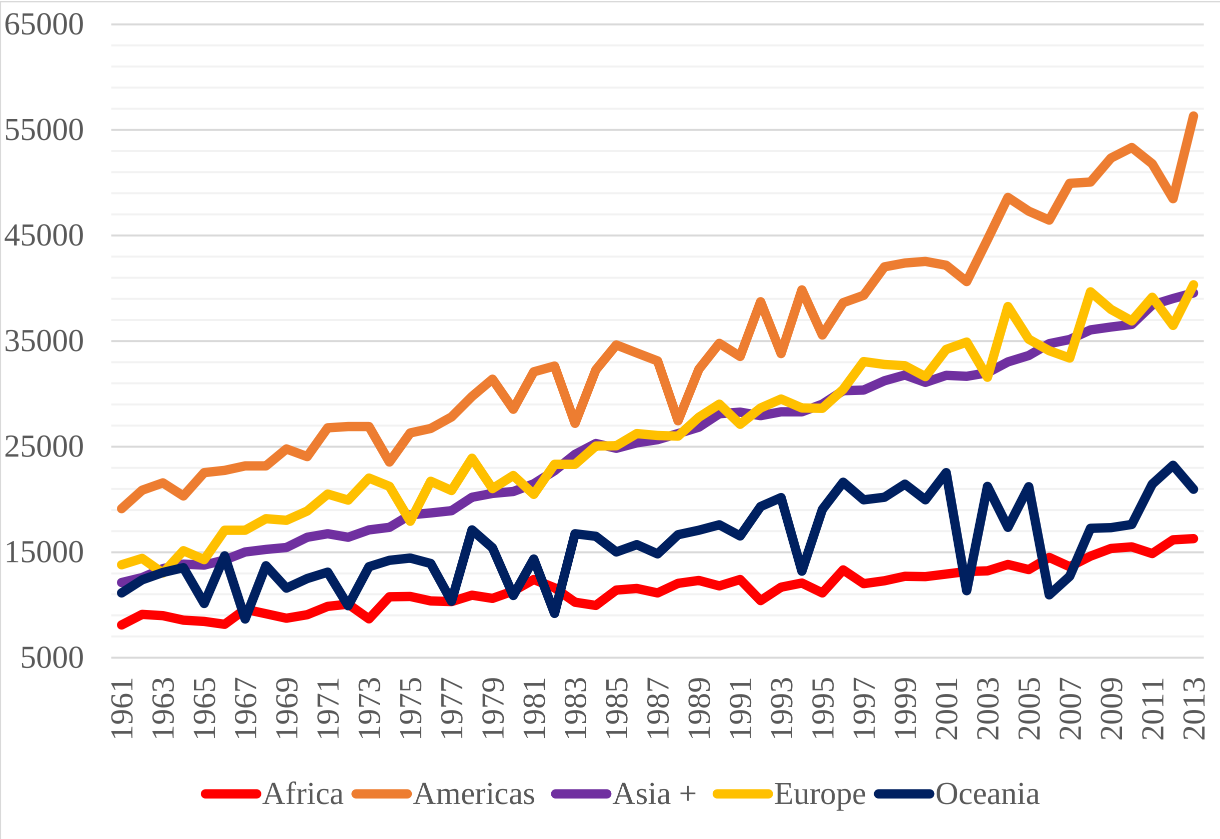
Zhou, P., Ang, B. W., & Han, J. Y. (2010). Total factor carbon emission performance: a malmquist index analysis. *Energy Economics, 32*(1), 194-201.

Zhu, J. (2016). *Data Envelopment Analysis: A Handbook of Empirical Studies and Applications* (Vol. 238). NewYork, NY: Springer Science and Business Media.

Zuberi, T., & Thomas, K. J. (2012). *Demographic projections, the environment and food security in Sub-Saharan Africa* (Working paper No. 001). Regional Bureau of Africa, United Nations Development Programme.

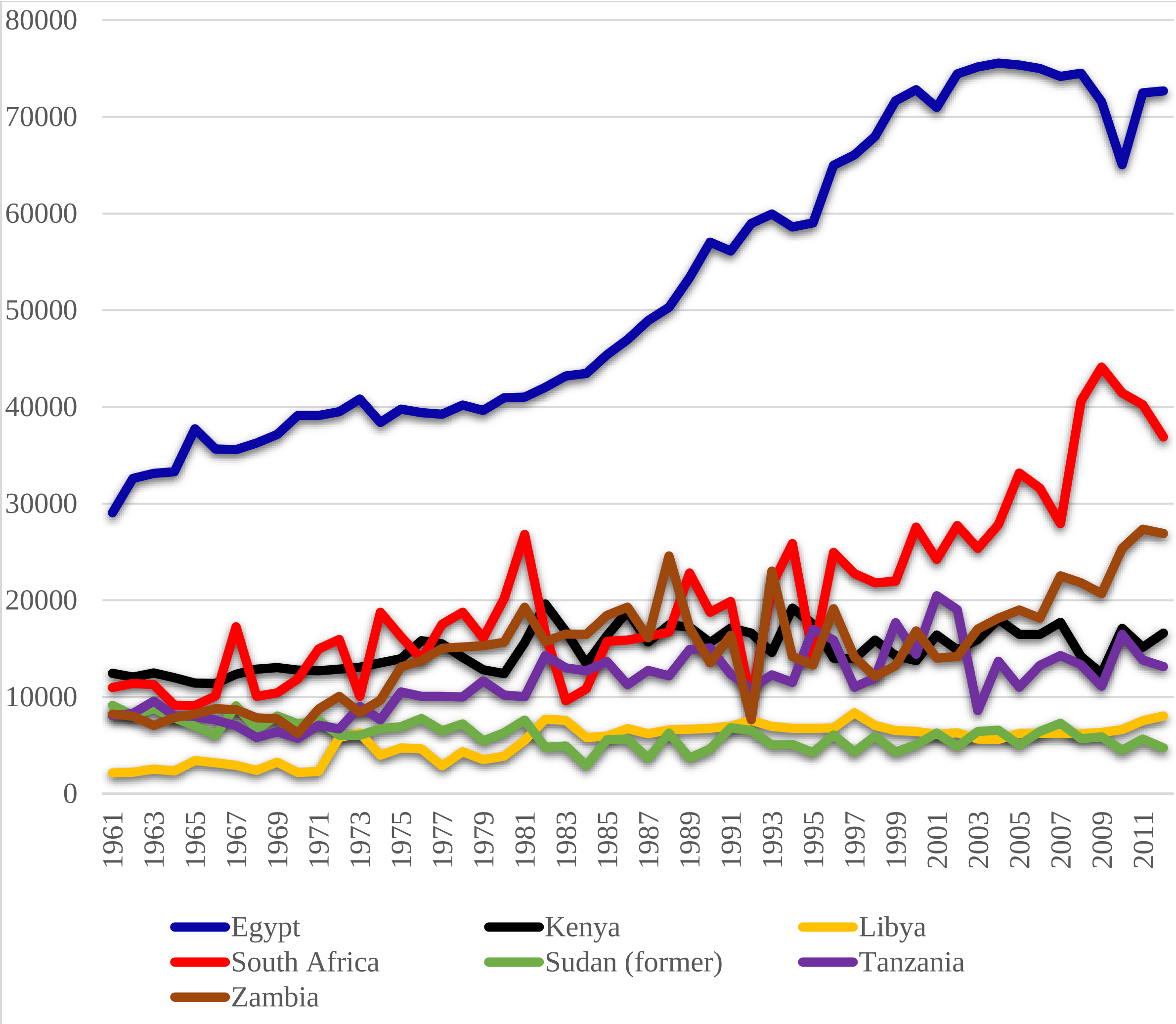
Appendices

Appendix A: Production per hectare of cereals in the regions of the world



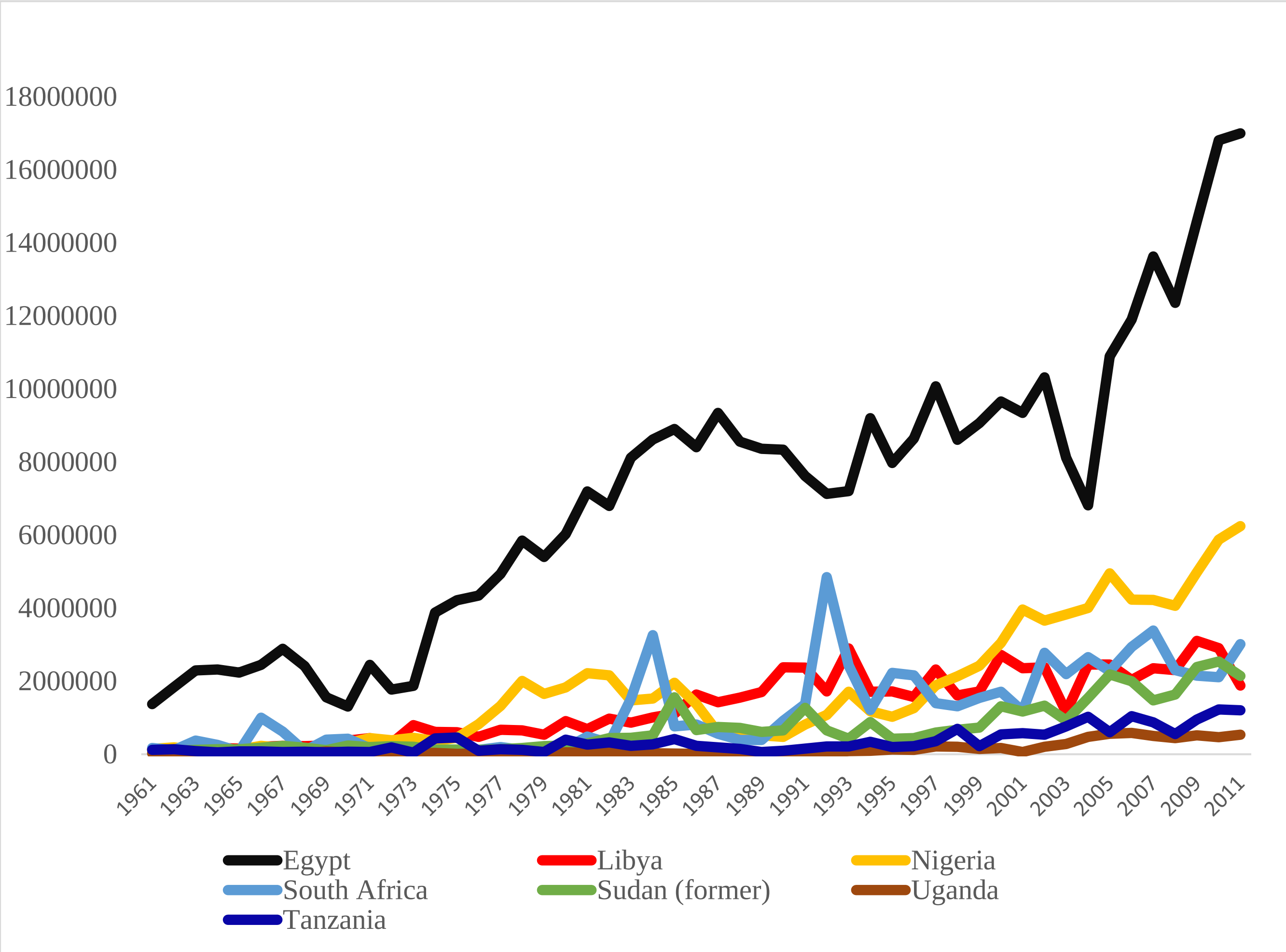
Source: FAOSTAT (2014)

Appendix B: Production per hectare of cereals in some selected African countries



Source: FAOSTAT (2014)

Appendix C: Cereal import to African countries



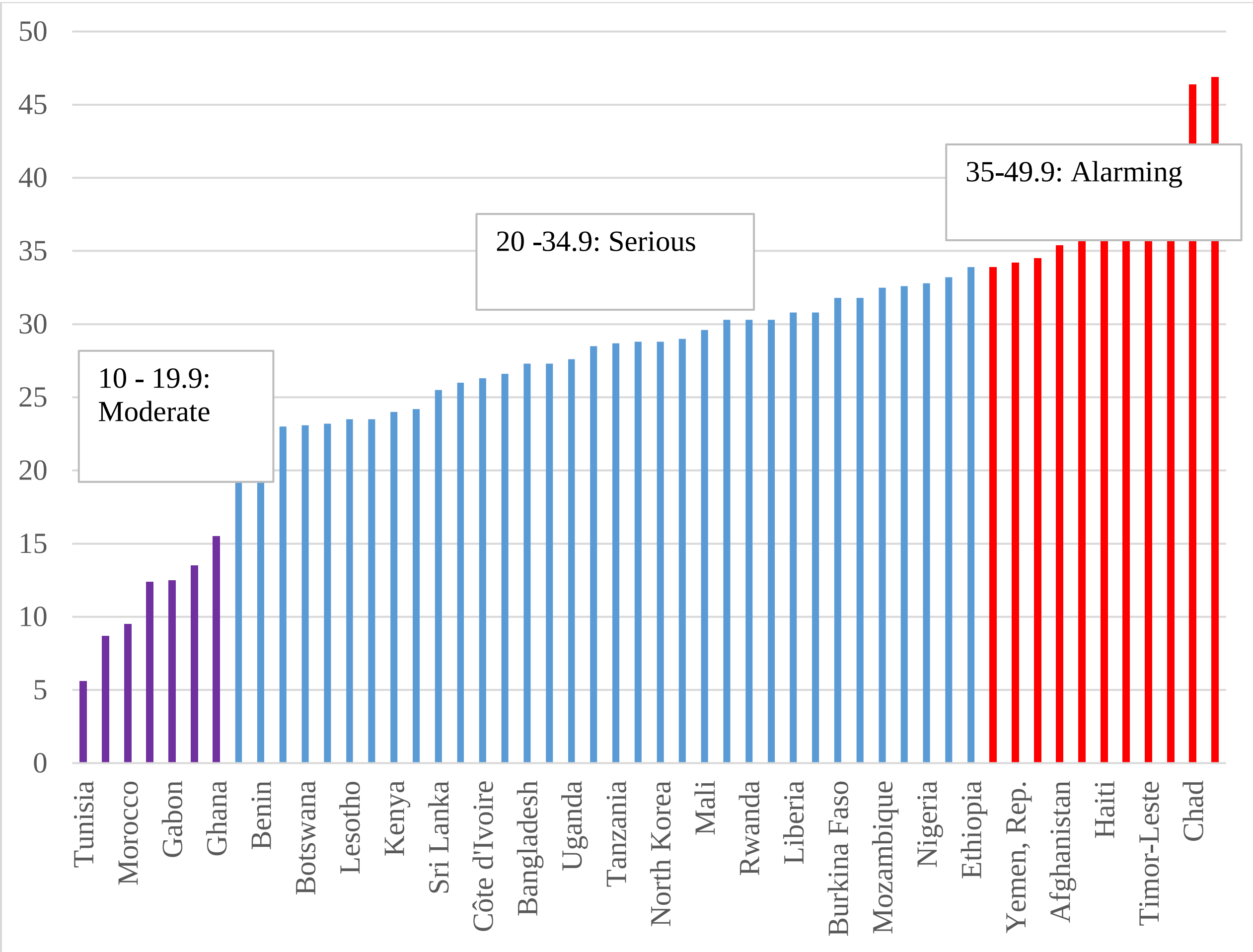
Source: FAOSTAT (2014)

Appendix D: Maps

D1: Map of Africa

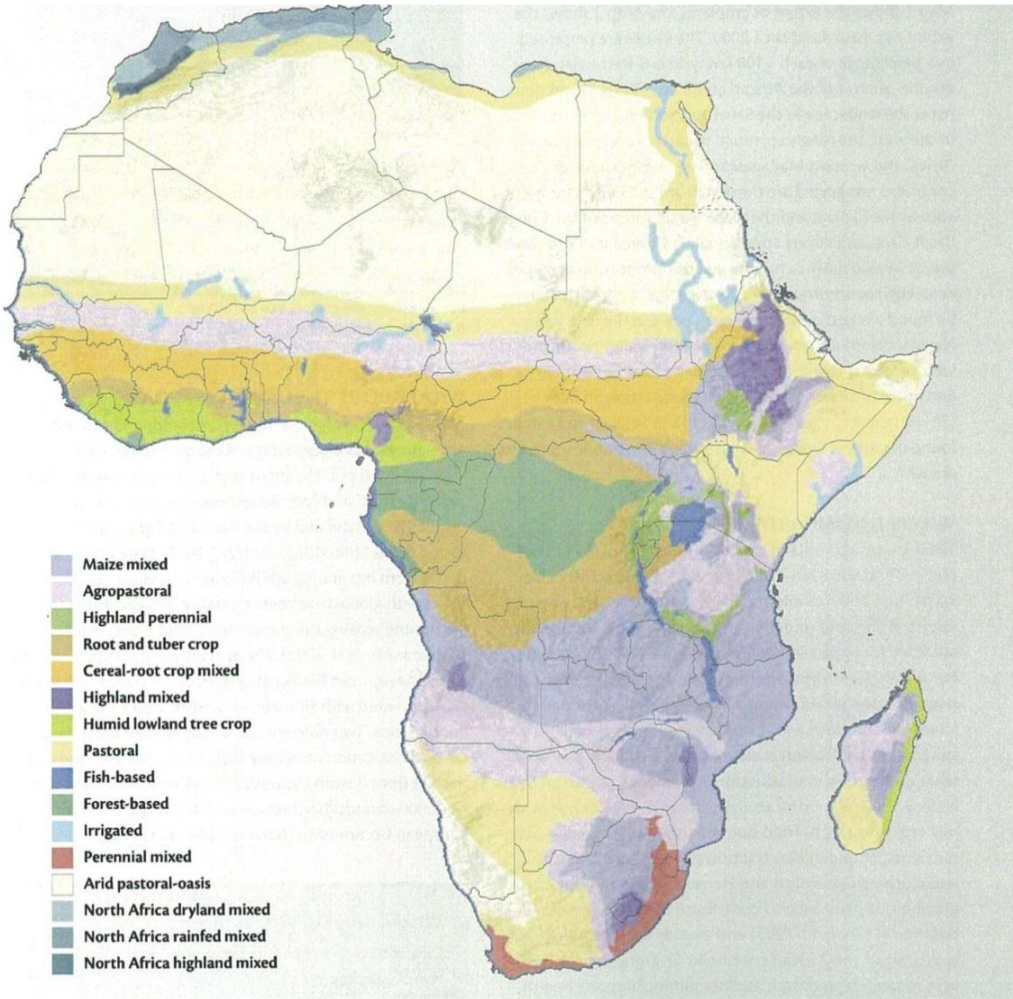
D2: Map of Kenya

Appendix E: 2015 Global Hunger Index



Source: IFPRI (2015)

Appendix F: Farming systems of Africa



Source: FAO

Appendix G: List of crops and livestock in different regions of Africa

Region	Countries	Major crops	Other crops	Cash crops	Livestock kept
Northern Africa	Algeria, Egypt, Libya, Morocco, Tunisia, Western Sahara and Sudan	Wheat, Barley, Maize, Pulses, rice	Olives, Almonds Tomatoes	Sisal hemp	Major are cattle, sheep, goats and camels. Poultry
Sahelian Africa	Benin, Burkina Faso, Costa Rica, Côte d'Ivoire, Togo, Liberia, Mali, Mauritania, Niger, Nigeria, Senegal, Sierra Leone, Gambia, Ghana, Guinea, Guinea Bissau	Sorghum, Millet, Maize, pulses, sugarcane and groundnuts	Oil palm fruit, cocoa, yams	Coffee, tea, cotton and rubber	Major are Cattle, sheep, goats and camels. Others are camelids, pigs, poultry, horses, donkeys,
Central Africa	Angola, Gabon, Democratic Republic of Congo, Central African Republic, Chad and Congo	Cassava, maize, groundnuts, pulses, sorghum	Plantains, coffee, cocoa	Cotton	Major are Cattle, sheep and goats Others are donkeys, camels, pigs and chickens
Eastern Africa	Burundi, Eritrea, Ethiopia, Kenya, Madagascar, Malawi, Mozambique, Rwanda, Somalia, Uganda, United Republic of Tanzania, Zambia and Zimbabwe	Maize, pulses, sorghum, cassava and sugarcane	Grapes, olives, dates	Coffee, tea, tobacco, cotton	Major are Cattle, sheep and goats Others are donkeys, camels, pigs and chickens
Southern Africa	Botswana, Lesotho, Namibia, South Africa and Swaziland	Maize, wheat, sunflower, sorghum, sugarcane	Grapes, oranges, pumpkins	Coffee, tea, tobacco, cotton	Major are camels, cattle, sheep, goats, pigs and chickens

Source: Areal et al. (2012) and other sources as referenced

Appendix H: Sources of emissions in various countries

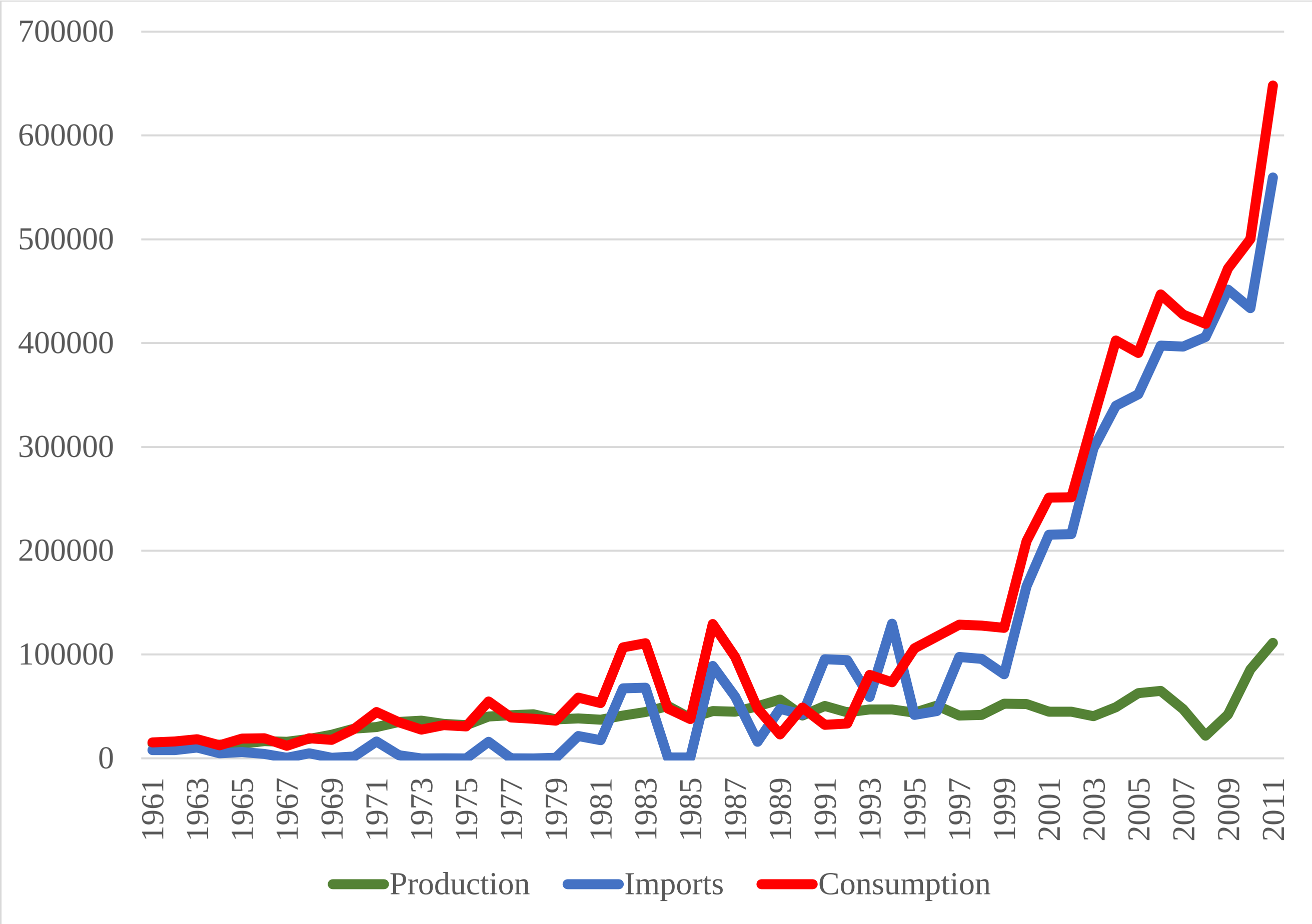
Country	Emissions from CO_2	Emissions from CH_4	Emissions from N_2O
Burundi	Enteric fermentation[6], manure left on pasture & cultivation of organic soils	Enteric fermentation	Manure left on pasture & cultivation of organic soils
Cameroun	Enteric fermentation, burning & manure left on pasture	Enteric fermentation	Manure left on pasture & burning
Côte d'Ivoire	Enteric fermentation, rice cultivation, manure left on pasture & burning	Enteric fermentation, manure management, burning of the savanna & rice cultivation	Manure left on pasture & burning
Gabon	Enteric fermentation, manure management, manure applied on soils & manure left on pasture	Enteric fermentation & burning	Manure left on pasture, burning and cultivation of organic soils
Gambia	Enteric fermentation, burning & manure left on pasture	Enteric fermentation, burning & rice cultivation	Manure left on pasture & burning
Ghana	Enteric fermentation, burning of the savanna & manure left on pasture	Enteric fermentation & burning	Manure left on pasture, burning & synthetic fertilisers
Kenya	Enteric fermentation & manure left on pasture	Enteric fermentation & manure management	Manure left on pasture, burning & synthetic fertilisers
Libya	Enteric fermentation, manure left on pasture, synthetic fertilisers & energy use	Enteric fermentation	Manure left on pasture and synthetic fertilisers
Madagascar	Enteric fermentation, rice cultivation, manure left on pasture & burning of the savanna	Enteric fermentation, & burning of the	Manure left on pasture, & burning of the savanna &

[6] Enteric fermentation is a digestive process that involves microbial breakdown of food into soluble products that can be utilised by the animal. The process is common particularly in ruminant animals such as cattle, sheep, goats and camels.

		savanna & rice cultivation	cultivation of organic soils
Malawi	Enteric fermentation, burning & manure left on pasture	Enteric fermentation	Manure left on pasture
Mozambique	Enteric fermentation, burning & manure left on pasture	Enteric fermentation & burning	Manure left on pasture & burning
Niger	Enteric fermentation, manure management, manure left on pasture & crop residues	Enteric fermentation & manure management	Manure left on pasture & crop residues
Nigeria	Enteric fermentation, manure left on pasture, rice cultivation & crop residues	Enteric fermentation, manure management, rice cultivation & burning	Manure left on pasture, manure applied to soils & crop residues
Sudan (former)	Enteric fermentation, manure left on pasture & burning	Enteric fermentation, manure management & burning	Manure left on pasture & burning
Togo	Enteric fermentation, manure left on pasture & burning	Enteric fermentation & burning	Manure left on pasture & burning
Tunisia	Enteric fermentation, manure left on pasture & energy use	Enteric fermentation & burning	Manure left on pasture & synthetic fertilisers
Tanzania	Enteric fermentation, manure left on pasture & burning	Enteric fermentation, rice cultivation & burning	Manure left on pasture, cultivation of organic soils & burning
Zambia	Enteric fermentation, manure left on pasture, cultivation of organic soils & burning	Enteric fermentation & burning	Manure left on pasture, cultivation of organic soils & burning

Source: FAOSTAT (2014)

Appendix I: Comparison of production, consumption and import of rice in Kenya



Source: FAOSTAT 2014

Appendix J: Ethics approval

QUT

University Human Research Ethics Committee (UHREC)

HUMAN RESEARCH ETHICS APPROVAL CERTIFICATE

NHMRC Registered Committee Number EC00171

Date of Issue: 1/3/16 (supersedes all previously issued certificates)

Dear Dr Boon Lee

This approval certificate serves as your written notice that the proposal has met the requirements of the *National Statement on Ethical Conduct in Human Research* and has been approved on that basis. You are therefore authorised to commence activities as outlined in your application, subject to any specific and standard conditions detailed in this document.

Project Details

Category of Approval: Negligible-Low Risk

Approved From: 25/03/2014 **Approved Until:** 25/03/2018 (subject to annual reports)

Approval Number: 1400000195

Project Title: Productivity, efficiency and adoption of technologies for improved livelihoods: Africa, with a special focus on Kenya

Investigator Details

Chief Investigator: Dr Boon Lee

Other Staff/Students:

Investigator Name	**Type**	**Role**
Prof Clevo Wilson	Internal	QUT Associate Supervisor
Mrs Eucabeth Bosibori Opande Majiwa	Student	Doctoral (Research)

Conditions of Approval

Specific Conditions of Approval:
No special conditions placed on approval by the UHREC. Standard conditions apply.

Standard Conditions of Approval:

1. Conduct the project in accordance with QUT policy, the ***National Statement on Ethical Conduct in Human Research*** (http://www.nhmrc.gov.au/guidelines/publications/e72), the ***Australian Code for the Responsible Conduct of Research*** (http://www.nhmrc.gov.au/guidelines/publications/r39), any associated legislation, guidelines or standards;
2. Gain UHREC approval for any proposed variation (http://www.orei.qut.edu.au/human/var/) to the project **prior** to implementation;
3. Respond promptly to the requests and instructions of UHREC;
4. Declare all actual, perceived or potential conflicts of interest;
5. Immediately advise the Office of Research Ethics and Integrity (http://www.orei.qut.edu.au/human/adv/) if:
   - any unforeseen development or events occur that might affect the continued ethical acceptability of the project;
   - any complaints are made, or expressions of concern are raised, in relation to the project;
   - the project needs to be suspended or modified because the risks to participants now outweigh the benefits;
   - a participant can no longer be involved because the research may harm them; and
6. Report on the progress of the approved project at least annually, or at intervals determined by UHREC. The Committee may also choose to conduct a random audit of your project.

If any details within this Approval Certificate are incorrect please advise the Research Ethics Unit within 10 days of receipt of this certificate.

End of Document

Appendix K: Letters of support

QUT Queensland University of Technology Brisbane Australia	LETTER OF SUPPORT FOR QUT RESEARCH PROJECT
EFFICIENCY OF RICE PRODUCTION, PROCESSING AND ADOPTION OF TECHNOLOGIES FOR IMPROVED LIVELIHOODS IN KENYA	
QUT Ethics Approval Number 1400000195	

1st April 2014

The Manager
National Irrigation Board
Mwea Irrigation Scheme
P.O Box Mwea, Kenya.

REF: REQUEST FOR SUPPORT FOR THE RICE FARMERS/PROCESSORS SURVEY

My name is Eucabeth Bosibori Opande Majiwa from Queensland University of Technology (QUT), Australia and I'm doing a PhD into rice farming and processing systems in Kenya. This study has been necessitated by the fact that the gap between rice production and consumption is huge. The above work is undertaken with a view to improving existing rice agricultural practices. Hence the results of the research will be useful in policy decision making in improving the livelihoods of farmers.

This is to request for your support to undertake my field survey in Mwea region. The fieldwork involves administering questionnaires to farmers/processors.

Your assistance in anyway will be highly appreciated.

Yours Faithfully

Beth

Mrs. Eucabeth Majiwa

ENDORSEMENT BY THE HEAD OF FIRM/DIVISION WHERE DATA WAS COLLECTED

Names Hosea Kipyegon Wendot Position Scheme Manager

Signature ______ Date and Official Rubber stamp ______

MWEA IRRIGATION SETTLEMENT
P. O. Box 80
TEL 48620 - WANG'URU

Queensland University of Technology Brisbane Australia	LETTER OF SUPPORT FOR QUT RESEARCH PROJECT

EFFICIENCY OF RICE PRODUCTION, PROCESSING AND ADOPTION OF TECHNOLOGIES FOR IMPROVED LIVELIHOODS IN KENYA

QUT Ethics Approval Number 1400000195

15th May 2014

The Senior Scheme Manager
National Irrigation Board
Western Kenya Schemes
P.O Box 101-40100, Kisumu, Kenya.

REF: REQUEST FOR SUPPORT FOR THE RICE FARMERS/PROCESSORS SURVEY

My names are Eucabeth Bosibori Opande Majiwa from Queensland University of Technology (QUT), Australia and I am undertaking a Doctor of Philosophy degree in Agricultural Economics. My research is on efficiency of rice production and processing systems in Kenya. This study has been necessitated by the fact that the gap between rice production and consumption is huge. The above work is undertaken with a view to improving existing rice agricultural practices. Hence the results of the research will be useful in policy decision making in improving the rice farming system of Kenya.

This is to request for your support to undertake my field survey in Ahero, West Kano and Bunyala Schemes. The fieldwork involves administering questionnaires to farmers and processors.

Your assistance in anyway will be highly appreciated.

Yours Faithfully

Beth

Mrs. Eucabeth Majiwa

ENDORSEMENT BY THE MANAGER OF THE SCHEMES WHERE DATA WAS COLLECTED

Names Laban K. Kiplagat Position Schemes Manager

Signature Date and Official Rubber stamp

SENIOR SCHEMES MANAGER
WESTERN KENYA SCHEMES
P.O. Box 1010 - 40100
KISUMU

26/5/014

Appendix L: Enumerator/translator confidentiality agreement form

Queensland University of Technology
Brisbane Australia

TRANSLATOR AGREEMENT FOR QUT RESEARCH PROJECT

EFFICIENCY OF RICE PRODUCTION, PROCESSING AND ADOPTION OF TECHNOLOGIES FOR IMPROVED LIVELIHOODS IN KENYA

QUT Ethics Approval Number 1400000195

RESEARCH TEAM CONTACTS

Eucabeth Bosibori Opande Majiwa, PhD Student

eucabethbosiboriopande.majiwa@qut.edu.au

Dr. Boon Lee, Senior Lecturer

boon.lee@qut.edu.au

Prof Clevo Wilson, Professor

clevo.wilson@qut.edu.au

School of Economics and Finance – QUT Business School – Queensland University of Technology (QUT)

THE AGREEMENT

As this research involves questioning individuals about rice farming and processing systems in Kenya, I the Principal Researcher in this project, require you to sign this translator confidentiality agreement.

As the enumerator/translator for this project you must:

- Keep all information related to this project secret and confidential.
- Not disclose to any person or make known in any manner any part of the project's information.
- Keep the project's information in a secure place to ensure that unauthorised persons do not have access to it.

SIGNATURES

This Agreement shall be effective when signed and dated by all parties.

Translator/ Enumerator	**Name**	……………………………………………………….
	Signature	……………………………………………………….
	Date	……………………………………………………….
Witness	**Name**	……………………………………………………….
	Signature	……………………………………………………….
	Date	……………………………………………………….

Appendix M: Participant information sheet

Queensland University of Technology Brisbane Australia	**PARTICIPANT INFORMATION FOR QUT RESEARCH PROJECT – Questionnaire (MAELEZO YA MSHIRIKI KATIKA KAZI YA UTAFITI YA QUT - Hojaji)**
EFFICIENCY OF RICE PRODUCTION, PROCESSING AND ADOPTION OF TECHNOLOGIES FOR IMPROVED LIVELIHOODS IN KENYA (UFANISI KATIKA UKULIMA WA MCHELE, UTAYARISHO WAKE NA UIGAJI WA TEKNOLOJIA KWA MINAJILI YA KUBORESHA MAISHILIO YA WANANCHI WA KENYA). **QUT Ethics Approval Number (Nambari ya Ithibati ya Kanuni za QUT) 1400000195**	

RESEARCH TEAM (JOPO LA WATAFITI)

Principal Researcher (Mtafiti Mkuu):	Eucabeth Bosibori Opande Majiwa, mwanafunzi wa PhD, Kitengo cha Masomo ya Uchumi na Fulusi, QUT
Associate Researcher (Watafiti wenza):	Dkt. Boon Lee, Mhadhiri Mkuu, Kitengo cha Masomo ya Uchumi na Fulusi, QUT na Prof. Clevo Wilson, Mhadhiri, Kitengo cha Masomo ya Uchumi na Fulusi, QUT

DESCRIPTION (MAELEZO)

This project is being undertaken as part of a Doctor of Philosophy requirement for Eucabeth Bosibori Opande Majiwa (Utafiti huu unafanywa kama hitaji la Eucabeth Bosibori Opande Majiwa katika masomo ya Shahada ya Uzamifu (PhD)).

The purpose of this project is to analysis the efficiency of production and processing, adoption of rice technologies and impact on livelihoods across the rice agro ecological zones of Kenya (Dhamira ya utafiti huu ni kuchunguza ufanis katika ukulima wa mchele, utayarisho wake na uigaji wa teknolojia za ukulima wa mchele na athari zake katika maishilio ya wakaazi wa maeneo ya kilimo ya mchele nchini Kenya).

You are invited to participate in this project because you are a rice processor (Unakaribishwa kushiriki katika utafiti huu kwa vile wewe ni msario wa mchele).

PARTICIPATION (KUSHIRIKI)

Participation will involve completing a questionnaire that requires personal information such as age, number of family members, production, experience, quantity, input details, environmental awareness questions with likert scale answers (Least important, Important, Very Important) that will take approximately up to one (1) hour of your time. Questions will include: how long you have been a rice processor? How much rice do you process per season? among others (Kushiriki kutahusisha kujaza hojaji inayodai habari zako binafsi kama umri, idadi ya watu katika familia yako, mazao yako, tajriba yako, kiasi cha mazao, pembejeo, maswali ya uelewa wa hamasisho za kimazingira yenye majibu ya ngazi. (isiyo na umuhimu, muhimu, muhimu kabisa). Maswali haya yatakuchukua muda wa karibu saa moja (1) kujaza? Baadhi ya maswali yatakuwa kama vile: umekuwa msario wa mchele kwa muda wa miaka ngapi? Mazao yako ya kusaga ni kiasi gani kila msimu)?

Your participation in this project is entirely voluntary. If you agree to participate you do not have to complete any question(s) you are uncomfortable answering. Your decision to participate or not participate will in no way impact upon your current or future relationship with QUT and National Irrigation Board (NIB). If you do agree to participate you can withdraw from the project without comment or penalty. However, as the questionnaire is anonymous once it has been submitted it will not be possible to withdraw (Kushiriki kwako ni kwa hiari. Ukikubali kushiriki, unaruhusiwa kupuuza maswali yanayokukwaza. Uamuzi wako kushiriki au kutoshiriki kamwe hautaathiri uhusiano wako wa sasa wala baadaye na QUT pamoja na Bodi la Kitaifa la Unyinyiziaji Maji. Ukikubali kushiriki, unaweza kujiuzulu bila kutoa maoni wala kuadhibiwa. Hata hivyo kwa vile hojaji haitambulishi mshiriki, baada ya kukabithiwa itakuwa vigumu kuiondoa).

EXPECTED BENEFITS (MANUFAA YANAYOTARAJIWA)

It is expected that this will not directly benefit you. However, it may be beneficial in supporting policy interventions aimed at increasing rice productivity and improve on rice processing and ensure that agricultural practices are environmentally sustainable in the rice farming communities of Kenya (Inatarajiwa kwamba hautafaidika kutokana na shuguli hii. Hata hivyo, itakufaidi pakubwa kusaidia katika ubuni wa sera zinazolenga kuimarisha mazao na matayarisho ya mchele na kuhakikisha kuwa ukulima uliopo katika jamii husika unaweza ukadumisha mazingira).

RISKS (HATARI)

There are no risks beyond normal day-to-day living associated with your participation in this project (Hakuna hatari zaidi katika ushiriki wako katika utafiti huu kuliko zile za maisha ya kilasiku).

PRIVACY AND CONFIDENTIALITY (USIRI WA UJUMBE WAKO)

All comments and responses will be treated confidentially unless required by law. The survey is anonymous which implies that the names of individual persons are not required in any of the responses. An audio recording will be done if you do not understand the Swahili language for audit purposes (Maoni yote na majibu yatawekwa faraga isipokuwa inapohitajika kutolewa kisheria. Utafiti huu ni faraga kwa hiyo majina ya washiriki hayahitajiki katika majibu yao. Iwapo una uelewa mdogo wa lugha ya Kiswahili kanda ya maswali itarekodiwa).

Any data collected as part of this project will be stored securely as per QUT's Management of research data policy. Please note that non-identifiable data collected in this project may be used as comparative data in future projects or stored on an open access database for secondary analysis Deta zote zitakazo patikana katika utafiti huu zitahifadhiwa salama kama inavyohitajika katika sheria za Usimamizi wa QUT. Zingatia kwamba deta zisizotambulisha mhojiwa zinazochukuliwa katika utafiti huu huenda zikatumika kama vilinganishi katika tafiti za baadaye ama kuwekwa kwenye mtandao kwa minajili ya uchunguzi.

The project is funded by Australia Awards Africa. This funding agency and any other body facilitating this research such as National Irrigation Board (NIB) will have not have access to the data obtained during the project (Utafiti huu umefadhiliwa na shirika la AusAID. Mfadhili huyu pamoja na wafadhili wengine wowote wa utafiti huu kama vile Bodi ya Kitaifa ya Unyunyunyiziaji Maji hawatapata deta zozote za utafiti huu).

CONSENT TO PARTICIPAT (IDHINI YA KUSHIRIKI)

The return of the completed questionnaire is accepted as an indication of your consent to participate in this project (Kurejesha hojaji iliyojazwa kikamilifu itakubaliwa kama ashiria ya idhini yako kushiriki katika utafiti huu).

QUESTIONS / FURTHER INFORMATION ABOUT THE PROJECT (MASWALI / MAELEZO ZAIDI KUHUSU UTAFITI HUU)

If have any questions or require further information, please contact one of the research team members below (Ikiwa una maswali yoyote au unahitaji maelezo zaidi tafadhali wasiliana na mmoja wa watafiti hapo chini).

Dkt. Boon Lee, Mhadhiri Mkuu, Kitengo cha Masomo ya Uchumi na Fulusi, QUT	Prof. Clevo Wilson, Mhadhiri, Kitengo cha Masomo ya Uchumi na Fulusi, QUT
Barua pepe: boon.lee@qut.edu.au	Barua pepe: clevo.wislon@qut.edu.au

CONCERNS / COMPLAINTS REGARDING THE CONDUCT OF THE PROJECT (SHAUKU / MALALAMISHI KUHUSU UENDESHAJI WA UTAFITI)

QUT is committed to research integrity and the ethical conduct of research projects. However, if you do have any concerns or complaints about the ethical conduct of the project you may contact the QUT Research Ethics Unit on [+61 7] 3138 5123 or email ethicscontact@qut.edu.au. The QUT Research Ethics Unit is not connected with the research project and can facilitate a resolution to your concern in an impartial manner. (QUT imejitolea kudumisha hadhi ya utafiti na kuhakikisha kuwa kanuni za uendeshaji wa utafiti zinazingatiwa. Hata hivyo, iwapo una shauku au malalamishi yoyote kuhusu kanuni za uendeshaji wa utafiti huu, wasiliana na Kitengo cha Kanuni za Utafiti cha QUT kupitia nambari za simu [+61 7] 3138 5123 au barua pepe ethicscontact@qut.edu.au. Kitengo hiki kin uhuru wa utendakazi wake na kwa hiyo kitaweza kutoa suluhisho la haki kwa malamishi yako).

Thank you for helping with this research project. Please keep this sheet for your information* (*Asante kwa usaidizi wako katika utafiti huu. Tafadhali hifadhi karatasi hii).

Appendix N: Consent form for participation

Queensland University of Technology, Brisbane Australia	**CONSENT FORM FOR QUT RESEARCH PROJECT** **(FOMU YA RUHUSA YA UTAFITI WA QUT)** **– Interview (Mahojiano)**

EFFICIENCY OF RICE PRODUCTION, PROCESSING AND ADOPTION OF TECHNOLOGIES FOR IMPROVED LIVELIHOODS IN KENYA (UFANISI KATIKA UKULIMA WA MCHELE, UTAYARISHO WAKE NA UIGAJI WA TEKNOLOJIA KWA MINAJILI YA KUBORESHA MAISHILIO YA WANANCHI WA KENYA).

QUT Ethics Approval Number (Nambari ya Ithibati ya Kanuni za QUT) 1400000195

RESEARCH TEAM CONTACTS (WASILISHI ZA JOPO LA WATAFITI)

Eucabeth Bosibori Opande Majiwa, manafunzi wa PhD, Kitengo cha Masomo ya Uchumi na Fulusi, QUT

Shule ya masomo ya Biashara, QUT

Simu

Eucabethbosiboriopande.majiwa@qut.edu.au

Dkt. Boon Lee, Mhadhiri Mkuu,

Kitengo cha Masomo ya Uchumi na Fulusi, QUT

Shule ya masomo ya Biashara, QUT

Simu

Boon.lee@qut.edu.au

Prof. Clevo Wilson, Mhadhiri,

Kitengo cha Masomo ya Uchumi na Fulusi, QUT

Shule ya masomo ya Biashara, QUT

Simu

clevo.wislon@qut.edu.au

STATEMENT OF CONSENT (TAARIFA YA IDHINI)

By signing below, you are indicating that you (Kwa kuweka sahihi hapo chini, unaarifu kuwa wewe):

- Have read and understood the information document regarding this project (Umesoma na kuelewa habari kuhusu mradi huu).
- Have had any questions answered to your satisfaction (Umetosheka na majibu yaliyotolewa kwa maswali uliyokuwa nayo).
- Understand that if you have any additional questions you can contact the research team (Unatambuwa kuwa iwapo una maswali zaidi unaweza ukawasailiana na jopo la watafiti).
- Understand that you are free to withdraw at any time, without comment or penalty (Unaelewa kuwa una uhuru wa kujiondoa kutoka kwa shuguli hii wakati wowote bila la adhabu yoyote).

- Understand that you can contact the Research Ethics Unit on [+61 7] 3138 5123 or email ethicscontact@qut.edu.au if you have concerns about the ethical conduct of the project (Unaelewa kwamba unaweza ukawasiliana na Kitengo cha Kanuni za Utafiti cha QUT kupitia nambari za simu [+61 7] 3138 5123 au barua pepe ethicscontact@qut.edu.au. Ukiwa na shauku au malalamishi yoyote kuhusu kanuni za uendeshaji wa utafiti huu).
- Agree to participate in the project (Unakubali kushiriki katika utafiti huu).

Name (Jina) ………………………………………………………………………………..

Signature (Sahihi) ………………………………………………………………………………..

Date (Tarehe) ………………………………………………………………………………..

Appendix O: Questionnaire – rice farmers

QUT Ethics Approval Number (Nambari ya Ithibati ya Kanuni za QUT) 1400000195

Date of Interview (Tarehe ya mahojiano) **………………………….**

Questionnaire No (Nambari ya hojaji**) ……………………….………**

Part A: Region details (Sehemu ya A: Maelezo ya eneo)

County (Jimbo) ……………………………………………

Sub-County (Mkoa) ……………………………………………….

District (Wilaya) …………………………………………

Division (Divisheni) ………………………………………………….

Location (Lokesheni) …………………………………….

Sub location (Lokesheni Ndogo) ………………………………….

Village (Kijiji)……………………………………………

Enumerator (Mwandishi) ……………………………………………

1.0 LAND USE (UTUMIZI WA ARDHI)

Q1a. How many **acres** in **total land holding** does the household **own (**Familia inamiliki ekari ngapi ya shamba kwa ujumala**)**? **_________**
Q1.1a. How many acres of land **were leased out** in the last **main season (**Ekari ngapi zilikodishwa msimu mkuu iliopita**)**? **_________**
Q1.1b. How many acres of land **were rented-in** in the last **main season (**Ekari ngapi zilikodishiwa watu msimu mkuu uliopita)? **_________**

Q1.1c. How many rice seasons are in this area (Kuna misimu ngapi ya ukulima wa mchele eneo hili)? ___________________

Q1.1d. If (1.1c) is one, when does the **main season start (**Iwapo jibu la 1.1c ni msimu mmoja, msimu huu huanza lini**)**? _________

ii. When does the **season end** (Msimu huu huisha lini)? ___________

Q1.1e. If (1.1c) is two, when does the **second season start (**Iwapo jibu la 1.1c ni misimu miwili, msimu wa pili huanza lini**)**? ______
ii. When does the short crop season end (Msimu huu huisha lini)? ____________

Q1.1f. Did this household have any cropping activity during **MAIN SEASON (**Familia hii ilipanda chochote katika msimu mkuu**)?** (1= Yes (Ndio) No (La)=2) ______

Q1.1g**.** Did this household have any cropping activity during **SHORT SEASON (**Familia hii ilipanda chochote katika msimu mfupi? (1=Yes Ndio 2=No La**) =** 2) **_________**

Season of rice farming (Msimu wa ukulima wa mchele) 1=Main (msimu mkuu) 2=Short (msimu mfupi)	Plot No (Nambari ya ploti)	Size of Plot in acres (Ukubwa wa ploti kwa ekari)	Soil type (Aina ya udongo)	Main land prep type (Njia kuu ya kutayarishia shamba). 0=none (Hakuna)0 1= manual (kwa mikono) 2= oxen (kutumia ng'ombe) 3= tractor (kutumia tingatinga) 4=herbicide (Dawa za magugu)	Total land preparation cost on this plot (Gharama kamili ya kutayarisha shamba katika ploti hii)?	Is this plot owned or leased (Ploti hii ni yako binafsi au wewe ni mpangaji)? 1=owned (Naimiliki) 2=leased (Nimepangisha)	If leased, how much do you pay per season in Ksh (Ikiwa wewe ni mpangaji, unalipa shiilingi ngapi kama kodi kila msimu)?

Q1.1h Source of water (Unyunyiziaji maji)

What is the source of water for rice farming on this plot (Chanzi ya maji ya kilimo katika ploti hii)? 1= Irrigation (Unyunyiziaji maji) 2= Rainfall (Mvua) 3= Borehole (Kisima) 4= Other specify (Njia tofauti, elezea) ……	If water source is irrigation how much do you pay for operation and maintenance (Iwapo unanyizia shamba lako maji, je unalipia maji hiyo pesa ngapi za operesheni na kudumisha)?	Do you experience water shortage in the farming period (Huwa unakumbwa na uhaba wa maji katika msimu wa kilimo)	If yes how many days was there no standing water (Iwapo jibu ni ndio, ni siku ngapi maji yalikosekana)?	How much did rice reduce due to water shortage (Mazao ya mchele yalipungua kwa kiwango ngani kutokana na uhaba wa maji)?

2.0 USE OF RICE SEED (MATUMIZI YA MBEGU ZA MCHELE)

Q2. Indicate the type of seed planted in the main and short season (Elezea aina ya mbegu zilizopandwa katika msimu mkuu na msimu mfupi)

Season of rice farming (Msimu wa kupanda mchele) 1=Main (msimu mkuu) 2=Short (msimu mfupi)	Plot Number (Nambar i ya ploti)	Seed Variety (Aina za mbegu)	Source of seed (Asili ya mbegu) 1= Nearest market (Soko la karibu) 2= Neighbour (Jirani) 3= Retained from last season (Salio za msimu uliopita)	Quantity Planted (Kiasi kilichopan dwa)	Seed Unit in Kg (Kifung u cha mbegu kwa kilo)	Cost per Kg (Bei ya kila kifungu)	Total cost (Garama kamili)	Mode of payment (Namna ya malipo) 1=Cash (Pesa taslimu) 2=Credit (Mkopo) 3= Donation (Msaada) 4= Other Specify (Njia tofauti, elezea) _____	For those farmers contracted to produce rice seeds (Kwa wale makandarasi wa kutoa mbegu ya mchele)			
									Quantity Harvested (Kiasi cha mavuno)	No of 90 kg bags harveste d (Kiasi cha gunia 90 cha mavuno)	Quantity Sold Kiasi kilichouzwa)	Price per bag (Bei ya gunia moja)

3.0 INPUT USE

Q3a. What **Fertiliser Input** did you use and what was the mode of purchase/acquisition (Ulitumia mbolea ipi na uliinunua/uliipata vipi)?

Input codes (Ashiria za Pembejeo) 1=DAP 2=MAP 3=TSP 4=SSP 5=NPK (20:20:0) 6=NPK (17:17:0) 7=NPK (25:5:+5S) 8=CAN (26:0:0) 9=ASN (26:0:0) 10=UREA (46:0:0) 11=SA (21:0:0) 13=Manure 14=Foliar feeds 15=NPK (23:23:23) 16=NPK (20:10:10) 17=DAP + CAN	21=NPK (23:23:0) 22=NPK (17:17:17) 23=NPK (18:14:12) 24=NPK (15:15:15) 25=Mavuno-basal 26=Kero green 27=Rock-phosphate 28=NPK 14:14:20 29=Mijingu 1100 30=UREA+CAN 31=Mavuno-top dress 32=NPK (22:6:12)	Season of rice farming (Msimu wa kupanda mchele) 1=Main (msimu mkuu) 2=Short (msimu mfupi)	Plot Number (Nambari ya ploti)	Acres planted (Ekari zilizolimwa)	Input Type Aina ya pembejeo)-select from list on the left side (chagua kutoka kwa orodha upande wa kushoto)	Input Unit (90 Kg bag) Kifungu cha pembeje kwa uzito wa kilo 90)	Cost per Bag (Garama ya gunia moja)	Source of Fertiliser (Wauzaji wa mbolea) **Source type codes (Ashiria za wauzaji)** 1=small trader (Wafanyibiashara wadogo) 2=Stockist (Wawekaji wa pembejeo) 3=large company (Kampuni kubwa) 4=CBO (Mashirika ya Kijamii) 5=KFA Chama cha Wakulima Kenya) 6=coffee coop (Ushirika wa Wakulima wa Kahawa) 7=farmer /neighbor (Mkulima/Jirani) 8=KTDA (Halmashauri ya Ukuzaji wa Majani Chai, Kenya) 9=Mwea Rice Growers and Millers Association (Ushirika wa Wakulima na Wasario wa Mchele, Mwea) 10=Relative or friend (Jamaa au rafiki) 11=Other organizations (Mashirika mengine) 12=others specify (Zingine, elezea)	Impact of use on **Output** (Athari za matumizi kwa **mazao)** 1=increased (Ongezeko) 2=decreased (Upungufu) 3=No change (Ukosefu wa athari zozote) 4=Other (Zingine) ___	Impact of use on **Environment** (Athari za utumizi kwa **mazingira).** 1=water source contamination (Uchafuzi wa vyanzo vya maji) 2=soil contamination (Uchafuzi wa udongo) 3=no change (Ukosefu wa athari zozote) 4=other specify (Zingine elezea) _____

18=NPK (25:5:0) 19=Magmax Lime 20=DSP										

Q3b. What **Chemical Inputs** did you use and what was the mode of purchase/acquisition (Ulitumia kemikali zipi na ulizinunua/ulizipata vipi)?

| Input Name (Jina la pembejeo) (Brand Name – Jina la brandi) | Input Type (Ashiria za pembejeo)

1=pesticide (Dawa za visumbufu)

2=insecticide (Dawa za wadudu)

3=herbicide (Dawa za magugu)

4=fungicide (Dawa za kungu) | Season of rice farming (Msimu wa kupanda mchele)

1=Main (msimu mkuu)

2=Short

(msimu mfupi) | Plot Number (Nambari ya ploti) | Acres planted (Ekari zilizoli mwa) | Amount applied (Kiasi cha kemikali kilichotu mika) | Input Unit (Kifungu cha penjeo) - No of kg /grams– Kiazi cha kilo ama grami) | Cost per unit (Garama ya kila kifungu) | Source of Chemical inputs

(Wauzaji wa kemikali)

<u>Source type codes (</u>Ashiria za wauzaji)

1=small trader (Wafanyibiashara wadogo)

2=Stockist (Wawekaji wa pembejeo)

3=large company (Kampuni kubwa)

4=CBO (Mashirika ya Kijamii)

5=KFA Chama cha Wakulima Kenya)

6=coffee coop (Ushirika wa Wakulima wa Kahawa)

7=farmer /neighbor (Mkulima/Jirani)

8=KTDA (Halmashauri ya Ukuzaji wa Majani Chai, Kenya)

9=Mwea Rice Growers and Millers Association (Ushirika wa | Impact of use on **Output** (Athari za matumizi kwa **mazao)**

1=increased (Ongezeko)
2=decreased (Upungufu)
3=No change (Ukosefu wa athari zozote)
4=Other (Zingine) ___ | Impact of use on **Environment** (Athari za utumizi kwa **mazingira).**
1=water source contamination (Uchafuzi wa vyanzo vya maji)
2=soil contamination (Uchafuzi wa udongo)
3=no change (Ukosefu wa athari zozote)
4=other specify (Zingine elezea) _____ | What was the **reason for use** (Sababu za kutumia kemikali)? |

								Wakulima na Wasario wa Mchele, Mwea) 10=Relative or friend (Jamaa au rafiki) 11=Other organizations (Mashirika mengine) 12=others specify (Zingine, elezea)			

Q3c. What **machinery/implement** did you use and what was the mode of purchase/acquisition (Ulitumia mashine/kifaa kipi na ulikinunua/ulikipata vipi)?

Machinery/ Implement Name (Jina la mashine /kifaa)	Is the machine/ implement (mashine /kifaa kime) 1=owned (kimemilikiwa) 2=borrowed (cha kuomba) 3=rented (cha kulipia)?	If owned number of years owned (Miaka ya kumilika)	If owned how much money did you purchase it? (Pesa zilizogarim u kunua)	Season of rice farming (Msimu wa kupanda mchele) 1=Main (msimu mkuu) 2=Short (msimu mfupi)	Plot Number (Nambari ya ploti)	Acres planted (Ekari zilizolimwa)	No of hours used (Muda uliotumika)	Cost per hr (Gharama kwa saa)	Total cost (Gharama Kamili)	Impact of use on **labour** (Athari za utumizi kwa kazi) 1=increased (Ongezeko) 2=decreased (Upungufu) 3=No change (Ukosefu wa athari zozote) 4=Other (Zingine) ___

Q3d. What **Other Inputs** did you incur and what was the mode of purchase/acquisition?

Input codes (Ashiria za pembejeo) 1=sprayer (Kirasha) 2=planter cost (Nauli ya kipandio) 3=transport (nauli) 4=fuel (mafuta) 5=gunny bags (magunia) 6=ridger cost (Kipalilio) 7=land rent (Kodi la shamba) 8=land preparation (Kutayarisha shamba) 9=farm implements (Kukodisha mashine/kifaa) 10=irrigation equipment (Kifaa cha kunyunywisha maji) 11=other, specify (Zingine elezea) ______	Season of rice farming (Msimu wa kupanda mchele) 1=Main (msimu mkuu) 2=Short (msimu mfupi)	Plot Number (Nambari ya ploti)	Acres planted (Ekari zilizolimwa)	Input Type Aina ya pembejeo)- select from list on the left side (chagua kutoka kwa orodha upande wa kushoto)	Input Unit/ No /Amount (Kifungu cha pembeje / Nambari /Kiazi)	Cost per unit (Garama ya kila kifungu)	Total cost (Gharama Kamili)	Source of other inputs (Wauzaji wa vifaa vingine) **Source type codes (**Ashiria za wauzaji) 1=small trader (Wafanyibiashara wadogo) ; 2=Stockist (Wawekaji wa pembejeo) ; 3=large company (Kampuni kubwa) 4=CBO (Mashirika ya Kijamii); 5=KFA Chama cha Wakulima Kenya); 6=coffee coop (Ushirika wa Wakulima wa Kahawa) 7=farmer /neighbor (Mkulima/Jirani); 8=KTDA (Halmashauri ya Ukuzaji wa Majani Chai, Kenya); 9=Mwea Rice Growers and Millers Association (Ushirika wa Wakulima na Wasario wa Mchele, Mwea); 10=Relative or friend (Jamaa au rafiki) 11=Other organizations (Mashirika mengine) 12=others specify (Zingine, elezea)

Q3e. Who makes decision on what inputs to purchase (Nani hufanya uamuzi wa pembejeo zitakazonunuliwa)? _______________

1= Male head (Mume) 2= Female Head (Mke) 3=Both head and spouse (Mke Mume na Mke

4=Other household male members (Waume wengine katika familia) 5=Other household female members (Wake wengine katika familia)

Q3f. How much did you contribute towards the final decision to what inputs to purchase? __________

1= None (Sikuchangia) 2 = 25% 3 = 50% 4 = 75% 5 = 100%

4.0 SOURCES OF CAPITAL (MITAJI)

Q4. On average, how much money did you spend on rice farming during the main season **(Ulitumia pesa ngapi katika ukulima wa mchele katika msimu mkuu)**? ____________________

Q4b. What were your sources of capital (W**ewe hupata wapi mitaji**)? _______________

1=Sales from rice (**Mauzo ya mchele)** 2=Income from other sources (**Mishahara mingine)** 3=Savings (**Arbuni)** 4=.Credit (**Mikopo)**
5=Donation (**Usaidizi)** 6. Others specify **(Zingine elezea)** ______

Q4c. If Q4b is credit, from which source did you obtain credit **(Iwapo jibu la Q4b ni mikopo, ilipewa na shgirika lipi)**? _________________________

1=Cooperative/Sacco (**Ushirika na mashirika ya arbuni na mikopo)** 2=Commercial Bank (**Benki za kibiashara)**

3=ROSCA (rotating savings and credit assoc) - **Vyama** 4=NGO/MFI (**Mashirika yasio ya kiserikali na yale madogo ya kifedha)**

5= Mwea Rice Growers and Millers Association (Ushirika wa Wakulima na Wasario wa Mchele, Mwea)

6=Relative/friend (**Jamaa/marafiki)** **7=**Informal money lender (**Mikopo ya mitaani)** 8=Other specify (Zingine elezea)
____

Q4d. How was the credit repaid **(Mkopo ulilipwa vipi)**? _________________________

1=Rice sales **(Mauzo ya mazao ya mchele)** 2=Other crop sales (**Mauzo ya mazao mengine shambani)** 3. Livestock sales (**Mauzo ya mazao ya mifugo)**
4=Off-farm income (**Mazao yasio ya shambani)** 5=Both crop and livestock income (**Mauzo ya mazao ya mifugo na mimea)** 6=Other Specify (Zi**ngine elezea)**________________________

Q4e. Are you a member of any group/cooperative that is involved in rice production/marketing (**Je, wewe ni mwanachama wa kikundi/shirika lolote linalohusika na ukulima wa mchele au mauzo yake**? ________________

1=Yes (Ndio) 2=No(La)

Q4eii. If Q4e is yes, which one (Iwapo jibu la Q4e ni ndio, ni shirika/ kikundi gani)? 1=Producer cooperative (Shirika la Wakulima) 2=Multi-purpose cooperative (Shirika la ujumla) 3=Savings and credit cooperative (Shirika la arbuni na mikopo) 4=Informal/ self-help group 5= Mwea Rice Growers and Millers Association (Ushirika wa Wakulima na Wasario wa Mchele, Mwea) 5. Other specify (Zingine elezea) ___________

Q4f. What services do you obtain from the group or cooperative (Unapata huduma zipi kutoka kwa kikundi hiki au shirika hili)?

0=None (Hakuna) 1=Training (Mafunzo) 2=Marketing (Uuzaji) 3=Input acquisition (Kupata pembejeo)

4=Financial services (Huduma za kifedha) 5=Buying household items (Ununzi wa bidhaa za nyumbani) 6=Other specify (Zingine elezea) ….

5.0 HARVEST AND SALE OF PADDY (MAVUNO NA MAUZO YA MBEGU ZA MCHELE)

Q5a. Indicate the method of harvest and quantity sold (Elezea mbinu za kuvuna na kiasi cha mauzo)

Season of rice farming (Msimu wa kupanda mchele) 1=Main (msimu mkuu) 2=Short (msimu mfupi)	Seed Variety (Aina za mbegu)	Quantity Harvested (Kiasi cha mavuno)	Unit of Harvest (Vifungu vya vuno) **Unit codes** **(Ashiria za mavuno)** 1=90 kg bag 2=50 kg bag 3=25kg bag 4=10kg Bag 5=gorogoro 6=tonnes 7=debe 8=kg	Harvest Method (Mbinu ya kuvuna) 1=Mechanical (mashine) 2=Manual (Kwa mkono) 3=Other Specify (Kutumia mbinu zingine, elezea)	Where do you store your paddy (Unahifadhi wapi mpunga)? 1= Store (Bohari) 2=House (Nyumbani) 3= Farm (Shambani) 4=Neighbor (Jirani) 5=Millers (Kwa Wasario) 6=Other Specify (Kwengine, elezea)	Quantity of paddy Sold (Kiasi kilichouzwa)	Unit of paddy Sale (Vifungu vya mauzo) **Unit codes** **(Ashiria za mavuno):** 1=90 kg bag 2=50 kg bag 3=25kg bag 4=10kg Bag 5=gorogoro 6=tonnes 7=debe 8=kg	Price per unit of paddy (Garama ya kila kifungu cha mpunga cha mauzo)	Total paddy sales (Gharama halisi ya mauzoya mpunga)	Do you mill the paddy for sale (Unasaga mpunga wa kuuza)?	If yes you mill what is the Quantity of paddy milled (Kama unasagani Kiasi ya gani ya Mpunga uliosaga?	Quantity of milled rice sold (Kiasi cha mchele unauza baada ya kusaga mpunga)? **Unit codes** **(Ashiria za mavuno):** 1=90 kg bag 2=50 kg bag 3=25kg bag 4=10kg Bag 5=gorogoro 6=tonnes 7=debe 8=kg	Price per unit of milled rice (Bei ya mchele)	Total sales (Gharama halisi ya mauzo)

Q5b. What are the rice by-products (Mazao ya ziada ya shamba la mchele ni)? _______________ bii. _____________ biii. ___________biv. ___________

Q5c. What are the rice waste products (Takataka ya ziada ya shamba la mchele ni? ______________bii. _____________ biii. ___________biv. ___________

Q5d. For each of the byproducts listed what quantity do you obtain (Ulipata kiasi gani ya kila pato la ziada liloorodheshwa) _____________ cii. _________________ ciii. _________________

Q5e. For each of the waste products listed what quantity did you obtain (Ulipata kiasi gani ya takataka la ziada liloorodheshwa)? _____________ cii. _________________ ciii. _________________

Q5f. How did you dispose of the waste products from rice (Ulizilikiza vipi zao hizi)? _____ 1=Burning (Kwa kuchoma) 2=Cooking fuel (Kuni za kupikia)

3=Manure (Mbolea) 4=Livestock feed (Chakula cha mifugo) 5= Others (Zingine)_______

6.0 TECHNOLOGY ADOPTION (UIGAJI TEKNOLOJIA)

Q6. What technologies have you adopted **(Umeziiga teknolojia zipi)**?

Technologies adopted (Teknolojia zilizoigwa) 1=Improved varieties (Uimarisho wa aina za mbegu) 2=Use of machinery (Utumizi wa mashine) 3=Organic manure application (Utumiaji wa virutubishi) 4= System of Rice Intensification (Mfumo mpya wa SRI) 5=Others, Specify (Zingine elezea) _______	Source of Information (Asili ya teknolojia) 1=farmers (Wakulima) 2=Extension officer (Ofisa wa kilimo) 3=Media (Vituo na ala za habari) 4=Researchers (Watafiti) 5 = field day demonstrations (Maonyesho ya kilimo) 6 = private organization (Mashirika ya kibinafsi) 7 = own experience (Ttajriba yako) 8=Other Specify (Zingine elezea) ______	What year did you first hear about the technology (Ni lini mwanzo wako kuskia kuhusu teknolojia hiyo)? 1=Before (Kabla ya) 1980 2=1981-1990 3=1991-2000 4=2001-2010 5=After (Baada ya) 2011	Year when you tried the new technology (Uliiiga teknolojia hii mwaka gani)? 1=Before (Kabla ya) 1980 2=1981-1990 3=1991-2000 4=2001-2010 5=After (Baada ya) 2011	Duration between hearing and first application of the technology (Muda kati ya kusikia kuhusu na kuiiga teknolojia)	What factors did you consider when adopting the technology (Ni hali zipi ulizozingatia ilipoiiga teknolojia)? 1=Technology Cost (Garama ya teknolojia) 2=Technology availability (Upatikanaji wa teknolojia) 3=Labour requirements (Mahitaji ya utendakazi wake) 4=Impact on environment (Athari kwa mazingira) 5=Impact on crop (Athari kwa mmea) 6=Impact on human health (Athari kwa afya ya binadamu) 7=Others, Specify (Zingine elezea) _______	Motivators to adoption of the technology (Msukumo wa kuiiga teknolojia) 1=Increased output (Oongezeko la mazao) 2=Use of less water (Kupungua kwa matumizi ya maji) 3=Lower pests and diseases (Kiasi kidogo cha visimbufu na magonjwa) 4=Lower input use (Utumiaji mdogo wa pembejeo) 5=Better rice quality (Mazao bora ya mchele) 6=Government support (Msaada kutoka kwa serikali) 7=Others, Specify (Zingine elezea)

Q6b. Who makes decision on what technology to adopt (Nani hufanya uamuzi wa teknologia ya kuiga)? _______________

1=Male head (Mume) 2=Female Head (Mke) 3=Both head and spouse (Mke Mume na Mke 4=Other household male members (Waume wengine katika familia) 5=Other household female members (Wake wengine katika familia)

Q6c. How much did you contribute towards the final decision to adopt the technology (Ulichangia asilimia gani katika uamuzi wa teknologia ya kuiga)?........

1= None (Sikuchangia) 2 = 25% 3 = 50% 4 = 75% 5 = 100%

Q6b. Who implements the adopted technology (Nani anatekeleza teknologia uliyoiga? _______________

1=Male head (Mume) 2=Female Head (Mke) 3=Both head and spouse (Mke Mume na Mke 4=Other household male members (Waume wengine katika familia) 5=Other household female members (Wake wengine katika familia)

7.0 TECHNOLOGY IMPACT (Health, Livelihood, Environment) - ATHARI ZA TEKNOLOJIA (Afya, Maisha, Mazingira)

Q7a. Did you take into consideration the impacts of the technology before you adopted it **(Je, ulizingatia athari za teknolojia hiyo kabla ya kuiga)**? ________

1=Yes **(Ndio)** 2=No **(La)**

Q7b. How did you rate the importance of the following aspects before adopting the technology **(Ulilinganisha vipi umuhimu wa vipengele vifuatavyo kabla ya kuiga teknolojia hiyo)**?

Aspects considered (Vipengele vilivyozingatiwa)	**Rating (Ulinganisho)** 1=Not important (Haina umuhimu) 2=Least Important (Umuhimu mdogo) 3=Important (Ina Umuhimu) 4=Very important (Umuhimu mkuu) 5=Extremely important **(**Umuhimu mkuu sana)
Impact on health (Athari kwa afya)	
Impact on crop (Athari kwa mimea)	
Impact on biodiversity such as fish (Athari kwa maisha ya viumbe vingine kama vile samaki)	
Impact on soil (Athari kwa udongo)	

7c. Have there been changes in the output since adopting the technology (Je, kuna mabadiliko katika mazao tangu kuiga teknolojia hiyo)? ____________

1= Yes (Ndio)   2=No (La)

7cii. If yes, how has the output changed (Ikiwa kuna mabadiliko, mazao yamebadilka vipi)? ____________ 1=Increased (Ongezeko)   2=Decreased (Upungufu)

7ciii. How much has the output changed (Mazao yamebadilika kwa kiasi gani)? ____________

7d. Have there been any changes in fertiliser use since adopting the technology (Je, kuna mabadiliko katika utumizi wa mbolea tangu kuiga teknolojia hiyo)?

1= Yes (Ndio)   2=No (La)

7dii. If yes, how has fertiliser use changed (Ikiwa kuna mabadiliko, utumizi wa mbolea umebadilika vipi)? ____________   1=Increased (Ongezeko)
2=Decreased (Upungufu)

7diii. How much has fertiliser use changed (Utumizi wa mbolea umebadilika kwa kiasi gani)? __________

7e. Have there been changes in seed use since adopting the technology (Je, kuna mabadiliko yoyote ya kiasi cha mbegu unazotumia tangu kuiga teknolojia hiyo)? _________

1= Yes (Ndio)   2=No (La)

7eii. If yes, how has seed use changed (mbegu unazotumia zimebadilika ajekwa kiasi gani)? ____________1=Increased (Ongezeko)   2=Decreased (Upungufu)

7eiii. How much has seed use changed (mbegu unazotumia zimebadilika kwa kiasi gani)? __________

7f. Have there been any changes in planting practises since adopting the technology (Je, kuna mabadiliko yoyote ya mbinu za upanzi tangu kuiga teknolojia hiyo) __________   1= Yes (Ndio)   2=No (La)

7fii. If yes, how has planting practices changed (Ikiwa kuna mabadiliko, mbinu za upanzi zimebadilika vipi)? __________   1=Plant seed less deeply (Mbegu zapandwa juujuu)   2=Reduced planting distance (Upanzi wa kukaribiana)   3=Change from broadcast to row planting (Kubadilisha upanzi kutoka usambazo hadi mpando)   4=Others Specify (Zingine, elezea) ……………

7g. Have there been changes in labour use since adopting the technology (Je, kuna mabadiliko yoyote ya kikazi tangu kuiga teknolojia hiyo) ____________

1= Yes (Ndio)   2=No (La)

7gii. If yes, how has the labour use changed (Ikiwa kuna mabadiliko, mazao yamebadilka vipi) ____________1=Increased (Ongezeko) 2=Decreased (Upungufu)

7giii.How much has the labour use changed (mabadiliko ya kikazi ni kiasi gani)? ____________

7h. Have there been changes in pesticide use since adopting the technology (Je, kuna mabadiliko yoyote ya dawa za visumbufu tangu kuiga teknolojia hiyo)? ____________

1= Yes (Ndio) 2=No (La)

7hii. If yes, how has the pesticide application changed (Ikiwa kuna mabadiliko, utumizi wa madawa ya visumbufu umebadilka vipi)? ____________1=Increased (Ongezeko) 2=Decreased (Upungufu)

7hiii.How much has the pesticide application changed (utumizi wa madawa ya visumbufu umebadilka kwa kiasi gani) ____________

7i. Have there been changes in water use since adopting the technology (Je, kuna mabadiliko yoyote katika utumizi wa maji tangu kuiga teknolojia hiyo)?

1= Yes (Ndio) 2=No (La)

7iii. If yes, how has the water use changed (Ikiwa kuna mabadiliko, mazao yamebadilka vipi)? ____________1=Increased (Ongezeko) 2=Decreased (Upungufu)

7iiii. How much has water use changed since adopting the technology (utumizi wa maji umebadilika kwa kiasi gani? ____________

8.0 LABOUR

Q8. What labour inputs did you use for **the <u>largest rice</u> field** for the main season**?**

		Hired Labour				Family Labour (adults)						Family Labour (children)		
Activity name (Shuguli)	Code (Ashiria)	# hired (idadi ya waajiriwa)	# of days (siku)	Ksh per person per day (Mshahara wa kila mmoja kwa siku)	Total Ksh by contract (Mshahara wote wa kandarasi)	# of males (Wanaume)	# of hours each (masaa ya kila mmoja)	Total Hours (Jumla ya masaa)	# of females (Wanawake)	# of hours each (masaa ya kila mmoja)	Total Hours (Jumla ya masaa)	# of children (Watoto)	# of hours each (masaa ya kila mmoja)	Total Hours (Jumla ya masaa)
	Activity	**LB01**	**LB02**	**LB03**	**LB04**	**LB05**		**LB06**	**LB07**		**LB08**	**LB09**		**LB10**

ACTIVITY CODES ASHIRIA ZA SHUGULI

1=nursery preparation (matayarisho ya vikore)

2=1^{st} plough (Palilizi la kwanza)

3=2^{nd} plough (Palilizi la pili)

4= harrow (Kulima)

5=bird scaring (Kufukuza ndege)

6=planting (Upanzi)

7=weeding (palilizo)

8=spraying (kupulizia)

9=fertiliser application (kuweka mbolea)

10= top dressing (kuongeza virutubishi)

11=2^{nd} weeding (palilizo ya pili)

12= irrigation (kunyunyizia maji)

13= propping/wiring/desuckering (kutegemeza)

14= spraying (kupulizia)

15=watchmen (walinzi)

16= harvesting (kuvuna)

17=pruning (kupagua)

18=dusting (kupulizia mimea dawa)

19= threshing and winnowing (kupura na kupeta)

20= grading (kupanga makundi)

21=watchman (wallinzi)

22= haul to storage (kusafirisha kwa ghala)

23=drying (kukausha)

24= bagging (kurejelea mbegu)

25= other specify (Zingine elezea) ______

0.0 ASSETS OWNED (MILKI)

Q9. Which of the following items have been acquired from the rice proceeds **(Kati ya vifuatavyo, ni vifaa vipi ambavyo vimenunuliwa kutokana na faida za ukulima wa mchele)?**

Type (Aina)	**Cost (ksh) (Garama (Ksh)**	**Present Value (ksh) (Thamani yake sasa (ksh)**	**Type (Aina)**	**Cost (ksh) (Garama(Ksh)**	**Present Value (ksh) (Thamani yake sasa (ksh)**
Permanent/Tile roofed house (Jengo la kudumu/matofari)			Plough (Jembe)		
Permanent/Iron sheet roofed house (Jengo la kudumu/ mabati)			Seed-cum fertiliser drill (Kifaa cha kupeketea mbegu pamoja na mbolea)		
Semi-Permanent house (Jingo la muda)			Sprayer/duster (Kipulizi)		
Mud walled house (Kibanda)			Bullock cart (Rukwama ya ng'ombe)		
Mud walled/grass thatched house (Kibanda/ ezeko)			Generator (Jenereta)		
Goats (Mbuzi)			Solar panel (Kitega nguvu za jua)		
Chicken (Kuku)			Water tanks (Tangi za maji)		
Cows (Ng'ombe)			Car (Gari)		
Sheep (Kondoo)			Motorcycle (Pikipiki)		
Donkey (Punda)			Bicycle (Baisikeli)		
Television (Runimga)			Furniture (Samani)		
Mobile Phone (Rununu)			Piped water (Maji ya mfereji)		
Radio (Redio)			Electricity (Nguvu za umeme)		
Computer (Arakilishi)			**Other Specify (Zingine, elezea)**		

10.0 DEMOGRAPHIC CHARACTERISTICS

Q10. We would like to know more about you and experience in farming.

Are you the Head of your household (Wewe ndiye kiongozi wa nyumba yako)? 1=Yes (Ndio) 2. No (La)	What is the gender of the head (Jinsia ya kiongozi)? 1=Male (Mume) 2=Female (Mke)	Gender status of the household head (Jinsia kamili ya kifamilia) 1=Married (Ameoa/Ameolewa) 2=Single (Hajaoa/Kuolewa) 3=Widowed (Amefiwa)	Age in years (Umri kwa miaka)	Number of years of schooling (Miaka ya masomo)	Number of household members (Idadi katika familia)	Years of experience in rice farming (Tajriba katika ukulima wa mchele)	Gender of technology decision maker (Muamuzi wa teknolojia ya kuigwa ni wa jinsia gani)? I. Male (Mume) 2. Female (Mke)	Gender of technology decision implementer (Jinsia ya Mtekelezaji wa teknolojia) I. Male (Mume) 2. Female (Mke)

11.0 LIVELIHOODS (HUMAN AND FINANCIAL ASSETS)

Q11. We would like to know more about other livelihood aspects

11a. How much of the rice produced is left for home consumption (Ni kiasi gani ya mchele unabakisha ya kutumia nyumbani)? _________

1=none (Hakuna) 2=2-5 bags (gunia) 3=over (Kupita) 5 bags (gunia) 4=all of it (yote)

11b. What is the proportion of rice consumed to your main diet (Ni asilimia ngapi ya kiwango cha mchele unayotumia nyumbani)? _________

1=0 (sufuri) 2=25% 3=50% 4=75% 5=100%

11bii. Did you run out of rice for home consumption produced from your farm at any given time during 2013 (ulikumbwa na upungufu wa mchele kutoka kwa shamba lako mwaka wa 2013)? _________

1=Yes (Ndio) 2=No (La)

11biii. When did you next harvest rice following the time you ran out (Ulivuna lini mwisho baada ya upungufu)? _________

1= after 1 month (Baada ya mwezi moja) 2= 2-4 months (Miezi mbili mpaka inne) 3= 6 months (Miezi sita) 4=1 year (Mwaka moja)

11biv. Did the running out of rice constitute a problem (Upungufu wa mchele nyumbani ulileta shida)? _________

1=Yes (Ndio) 2=No (La)

11bv. Did you buy rice to cover for the shortage (Ulinunua mchele kupunguza upungufu)? **buyrice_________**

1=Yes (Ndio) 2=No (La)

11c. Do you have other sources of income apart from rice farming (Je, una mapato mengine kanndo na ukulima wa mchele)? _________

1=Yes (Ndio) 2=No (La)

11d. What are the other income sources (Mapato mengine ni yapi)?

1=Other crops (Mmea zingine) 2=Dairy (Maziwa) 3=Other livestock income (Mapato ya mifugo wengine)

4=Non-farm income (Mapato kando na ya ukulima 5=Others, specify (Zingine elezea) _______________

11e. What proportion of your total household income is from crop farming (Kiasi gani ya mapato ya familia yako hutokana na ukulima)? ___________

11f. What proportion is rice income to the total household income (Mapato ya mchele ni asilimia gani ya jumla ya mapato katika familia yako) _______________

11g. What is the proportion of non-farm income to the total household income (Mapato kando na ukulima ni asilimia gani ya jumla ya mapato katika familia yako)? _______

11h. Who is responsible for decision making on use of proceeds/income from rice (Ni jukumu la nani kufanya uamuzi wa jinsi mapato ya mchele yatakavyotumika) _______

1=Male head (Mume) 2=Female Head (Mke) 3=Both head and spouse (Mke Mume na Mke 4=Other household male members (Waume wengine katika familia) 5=Other household female members (Wake wengine katika familia)

11i. How much did you contribute towards the final decision on use of proceeds/income from rice (Ulichangia asilimia gani katika uamuzi wa jinsi mapato ya mchele yatakavyotumika)? _____________

1= None (Sikuchangia) 2=25% 3=50% 4=75% 5=100%

11j. How was the income from rice sales spent/ utilised (Mapato ya mauzo ya mchele yalitumika vipi)?

S. No (Nambari)	**Type of expenditure (Aina ya masarifu)**	**Amount of money spent per month (Ksh) (Kiasi cha pesa kinachotumika kila mwezi**	**Amount of money spent per year (Ksh) (Kiasi cha pesa kinachotumika kila mwaka**
	Item (Sarifu)	Amount (Kiasi)	
1	Food (Chakula)		
2	Clothing (Mavazi)		
3	Health expenses (Afya)		
4	Household utilities expenses (Mafaa ya kinyumbani)		

5	Payment for education (Malipo ya karo za shule)		
6	Development projects in the home (Miradi ya maendeleo nyumbani)		
7	Savings (Arbuni/Maweko)		
8	Others specify (Zingine elezea) ………………..…		

12.0 INFRASTRUCTURE MUUNDOMBINU (Distance should be recorded in kilometres-Hatua inapaswa kurekodiwa katika kilomita)

Q 12. Distances from your homestead (Hatua kutoka nyumbani kwako)

a. What is the distance from your homestead to where you buy **farm inputs (**Ni umbali upi kutoka nyumbani hadi? unakonunua mahitaji ya shamba)? **FERTKM** __________

b. What is the distance from your homestead to the nearest **fertiliser seller (**Ni umbali upi kutoka nyumbani hadi unakonunua mbolea)? **FERTSKM** __________

c. What is the distance from your homestead to where you buy rice seed (Ni umbali upi kutoka nyumbani hadi unakonunua mbegu)? **SEEDSKM** __________

d. What is the distance from your homestead to a **motorable road (**Ni umbali upi kutoka nyumbani hadi barabara? **DMTROAD** ________

e. What is the distance from your homestead to a **tarmac road (**Ni umbali upi kutoka nyumbani hadi barabara ya lami)? **DTMROAD** ________

f. What is the distance from your homestead to a **matatu/bus stop (**Ni umbali upi kutoka nyumbani hadi pahali pa kuabiria matatu)? **DMSTOP** ________

g. What is the distance from your homestead to the nearest **piped water (**Ni umbali upi kutoka nyumbani hadi pahali palipo na maji ya mfereji? **DPH2O** ________

h. What is the distance from your homestead to the nearest **health centre (**Ni umbali upi kutoka nyumbani hadi zahanati ya karibu)? **DHLTCTR** ________

i. What is the distance from your homestead to the nearest **electricity supply (**Ni umbali upi kutoka nyumbani hadi palipo na stima)? **DELECT** ________

j. What is the distance from your homestead to the nearest **mobile services (**Ni umbali upi kutoka nyumbani hadi palipo na huduma za simu ya rununu)? **DMOBILE** ________

k. What is the distance from your homestead to **extension advice (**Ni umbali upi kutoka nyumbani hadi alipo afisa wa kilimo)? **DEXTN**_____________

l. What is the distance from your homestead to the nearest **primary school (**Ni umbali upi kutoka nyumbani hadi shule ya msingi ya karibu)? **DPRISCH** ____________

m. What is the distance from your homestead to the nearest **secondary school (**Ni umbali upi kutoka nyumbani hadi shule ya upili ya karibu? **DSECSCH** ____________

n. What is the distance from your homestead to the nearest market place (Ni umbali upi kutoka nyumbani hadi sokoni)? **DMKT** _________

m. How often does this market operate (Soko hili huendesha shuguli zake mara ngapi)? ______________

1=Once a week (Mara moja kwa wiki) 2=Every day (Kila siku) 3=Twice a week (Siku mbili kwa wiki)

4=Once a month (Siku moja kwa mwezi 5=Other specify (Zingine, elezea) _________

n. What is the road type to the nearest market place (?

1=Tarmac (Lami) 2=Gravel/Murrum (Mchanga) 3=Mud (Matope) 4. Other specify (Zingine elezea) ___________

Q13. Do you face following common challenges as a rice farmer (Je unakumbwa na changamoto hizi za kawaida kama mkulima wa mchele)?

Input costs (Garama ya pembejeo)	**Output price (**Bei ya mazao)	**Infrastructure (**Muundombinu)	**Technology (**Teknolojia)	**Support services (**Hudumu za kimsingi)
High fertiliser prices (Bei za juu za mbolea)	Low output price (Bei ya chini ya mazao)	Lack of storage facilities (Ukosefu wa maghala)	High incidences of pests and diseases (Mkurupuko wa magonjwa na visumbufu)	Lack of extension services (Ukosefu wa huduma za afisa wa kilimo)
High pesticide prices (Bei kali ya madawa ya visumbufu)	Lack of reliable market for rice (Ukosefu wa soko za mchele za kutegemewa)	Insufficient irrigation water (Upungufu wa maji ya kunyunyiziza shambani)	Poor soils (Udongo mbovu)	Poor access to credit (Ukosefu wa huduma za mikopo)
High labour costs (Garama za juu za kazi)	Others specify (Zingine elezea) ………	Poor roads (Barabara mbovu)	Lack of suitable machinery (Ukosefu wa mashine mwafaka)	Others specify (Zingine elezea)
Others specify (Zingine elezea) ………		Others specify (Zingine elezea) ………	Others specify (Zingine elezea) ………	

1 = Yes   2 = No

Q13.b Which are the notorious pests that attack your crop (Ni aina gani ya wadudu wasumbufu)?

12bi___________________ 12bii. _______________________ 12biii______________________

12biv__________________

Q13.c Which are the notorious diseases that attack your crop (Ni aina gani ya magonjwa wasumbufu)?

12ci___________________ 12cii._______________________ 12ciii______________________

12civ__________________

Thank you for taking your time to participate in this study.

Appendix P: Questionnaire – rice millers

QUT Ethics Approval Number (Nambari ya Ithibati ya Kanuni za QUT) 1400000195

Date of Interview (Tarehe ya mahojiano) **…………………………..**

Questionnaire No (Nambari ya hojaji**)………………………..………**

Part A: Region details (Sehemu ya A: Maelezo ya eneo)

County (Jimbo) ……………………………………………

Sub-County (Mkoa) …………………………………………………

District (Wilaya) …………………………………………

Division (Divisheni) ………………………………………………….

Location (Lokesheni) ……………………………………..

Sub location (Lokesheni Ndogo) …………………………………

Village (Kijiji)……………………………………………

Enumerator (Mwandishi) ……………………………………………

1.0 BUSINESS DETAILS (MAELEZO YA BIASHARA)

Name of business (Jina la Biashara)	**When was this rice business started (Biashara hii ya mchele ilianzishwa lini)?** 1=Less than 1 yr (Haijapita mwaka mmoja) 2=1-5 yrs (Kati ya mwaka 1-5) 3=Over 5 yrs (Zaidi ya miaka 5)	**Where the business is located (Biashara yako iko wapi)?** 1=Within home premises (Nyumbani) 2=Outside home premises (Mtaani)	**Do you own the space occupied by the business (Je, unamiliki pahali biashari ipo)?** 1.Yes 2. No	**If premise is rented how much is the rent per month (Ikiwa umepangisha, unalipa kodi ya pesa ngapi kila mwezi)?**	**On average, how many days/months do you operate in a year (Kwa kawaida unafanya kazi siku/ miezi ngapi kwa mwaka)?**

2.0 PERSONAL DETAILS (MAELEZO YAKO)

Are you the owner or operator (Wewe ndio msario ama mwajiriwa)? 1=Owner (Msario) 2= Operator (Mwajiriwa)	**Gender (Jinsia)** 1=Male (Mwanaume) 2=Female (Mwanamke)	**Age (Umri) (yrs- miaka)**	**Head of household (Kiongozi wa familia)?** 1=Yes (Ndio) 2= No (La)	**No of household members (Idadi ya watu katika familia)**	**Number of years of schooling (Miaka ya kisomo)**	**Number of years of experience as a rice processor (Tajriba katika biashara ya mchele)**

3.0 MACHINERY (MASHINE)

3a. What machinery do you own for rice processing (Unamilki mashine ipi kutayarisha mchele)?

S. No (Nambari)	**Type of machinery (Aina ya mashine)**	**Cost at purchase (Bei iliponunuliwa)**	**Machine Capacity (Uwezo wa mashine)**	**No of Hrs used (Mda wa matumizi)**	**No of years used (Imetumika miaka ngapi)**	**Frequency of servicing (Inarekebishawa marangapi)**	**Total cost of maintenance (Garama ya kudumisha)**

4.0 LABOUR (KAZI)

4a. What type of labour do you use (unatumia wafanyakazi wa aina gani)?

Type (Aina)	No of workers (Idadi ya wafanyakazi)	No. of days (Idadi ya masiku)	Wage rate (Kiasi cha mshahara)	Total wages (Jumla ya mshahara)
Casual (Wa muda)				
Contract (Wa kandarasi)				
Permanent (Wa kudumu)				
Family (Familia)				
Others Specify (Zingine elezea)				

4b. What is the highest level of education for your employees (Waajiriwa wako wana kisomo kipi)?

Level (Kiwango)	No. of yrs of schooling (Miaka ya masomo)	No of workers (Idadi ya waajiriwa)
1=No Education (Wasiosoma)		
2=Primary School (Shule ya msingi)		
3=Secondary School (Shule ya upili)		
4=Vocational Training (Shule ya ngumbaro)		
5=University training		
6=Others Specify (Zingine elezea)		

5.0 PADDY (MPUNGA)

How much paddy do you buy for processing per season? (kg/tonnes) - Wewe hununua mpunga kiasi gani (kilogramu/tani) **<u>Unit codes</u> (Ashiria za mavuno)** 1=90 kg bag 2=50 kg bag 3=25kg bag 4=10kg Bag 5=gorogoro 6=tonnes 7=debe 8=kg	**No of units Purchased (Nambari yaVifungu)**	**How much do you buy the paddy in Ksh per unit (Wewe hununua kila kifungu kwa shilingi ngapi)?**	**What type of transport do you use (Wewe husafirisha vipi?** 1= Car (Gari) 2=Oxen (Ngombe) 3=Donkey (Punda) 4= Others specify (Zingine, elezea)	**How much do you incur to transport paddy (Wewe hugaramika kwa kiasi gani kusafirisha mpunga)?**	**Do you have a store for the paddy and processed rice (Je, una hifadhi ya mpunga)?** 1=Yes (Ndio) 2=No (La)	**What is the size of the store in ft (Ghala lako ni la ukubwa gani)?**

6.0 ENERGY (NISHATI)

6a. What type of energy do you use for rice processing (Unatumia nishati ipi kutayarisha mchele)?

S. No (Nambari)	**Type of Energy (Aina ya nishati)**	**Purpose (Dhamira/Matumizi)**	**Amount used (Kiasi kitumikacho)**	**Total cost (Ksh- Garama kamili)**
1	Electricity (Umeme)			
2	Fuel (Mafuta)			
3	Solar (Jua)			
4	Firewood (Kuni)			
5	Others Specify (Zingine (elezea)			

7.0 OUTPUT (MAZAO)

How many kilograms of rice do you process per month/year (Wewe hutayarisha kilo ngapi ya mchele kila mwezi/mwaka)?	How many kg/bags do you sell per month (Wewe huuza kilo/mifuko ngapi ya mchele kwa mwezi)?	What is the cost of milling per unit of rice in Ksh (Garama ya kutayarisha kifungu cha mchele ni shilingi ngapi)?	How much of the processed rice is left for family consumption (Ni kiasi kipi cha mchele husalia kwa ulaji wa familia)?	What kind of waste do you generate from processing rice (Wewe hupata aina gani ya mazao baada ya kutayarisha mchele)?	How do you dispose the generated waste (Mazao haya hutupwa vipi)?

Q7b. What are the other paddy by-products (Mazao mengine ya mpunga ni)? ________________ bii. ______________ biii. ____________biv. ___________

Q7c. What are the paddy waste products (Takataka ya ziada ya mpunga ni)? _______________bii. ______________ biii. ____________biv. ___________

Q7d. For each of the waste products listed what quantity did you obtain (Ulipatagredi gani kwa kila zao iliyoorodheshwa) ______________ cii. __________________ ciii.__________________

Q7e. How did you dispose of the waste products from the paddy (Ulizilikiza vipi taka hizi)? _____1=Burning (Kwa kuchoma) 2=Cooking fuel (Kuni za kupikia) 3=Manure (Mbolea) 4=Livestock feed (Chakula cha mifugo) 5= Others (Zingine)_______

8.0 ACCESS TO MARKETS (PENYENYE ZA SOKO)

Where do you source your paddy from (Wewe hupata mbegu zako wapi)? 1=Nearest farmers (Wakulima wakaribu) 2=Nearest local market (Soko la mtaani) 3=Nearest city market (Soko la mjini) 4=Agents (Ajenti) 5=Own farm (Shambani mwako) 6. Others Specify) (Zingine, elezea).	Where do you source inputs from? 1=Nearest farmers (Wakulima wakaribu) 2=Nearest local market (Soko la mtaani) 3=Nearest city market (Soko la mjini) 4=Agents (Ajenti) 5=Own farm (Shambani mwako) 6. Others Specify) (Zingine, elezea).	Where do you sell your processed rice? 1=Nearest farmers (Wakulima wakaribu) 2=Nearest local market (Soko la mtaani) 3=Nearest city market (Soko la mjini) 4=Agents (Ajenti) 5=Own farm (Shambani mwako) 6. Others Specify) (Zingine, elezea).	What is the distance in kms from the business to the nearest market (Ni umbali gani kutoka shambani hadi sokoni)?	How often does this market place operate (Soko hili hufunuguliwa kwa bishara mara ngapi)? 1= Everyday (Kila siku) 2=Once a week (Mara moja kwa wiki) 3=Twice a week (Mara mbili kwa wiki) 4=Once a month (Mara moja kwa mwezi) 5=Others specify (Zingine elezea).	How is the road network from the business to the nearest market (Barabara za kutoka mahali pa biashara kuelekea sokoni ziko katika hali gani)? 1=Tarmac (Lami) 2=Gravel (Changarawe) 3=Earth (Udongo) 4=Others specify (Zingine elezea)

9.0 SOURCES OF CAPITAL (MITAJI)

Q9a. On average, how much money did you spend on rice processing during the main season (Ulitumia pesa ngapi kutayarisha mchele katika msimu mkuu)? ____________________

Q9b. What were your sources of capital (W**ewe hupata wapi mitaji**)? 1=Sales from rice (**Mauzo ya mchele)** 2=Income from other sources (**Mishahara mingine)** 3=Savings (**Arbuni)** 4=.Credit (**Mikopo)** 5=Donation (**Usaidizi)** 6. Others specify **(Zingine elezea)** ______

Q9c. If Q9b is credit, from which source did you obtain credit **(Iwapo jibu la Q4b ni mikopo, ilipewa na shgirika lipi)**? _________________________

1=Cooperative/Sacco (**Ushirika na mashirika ya arbuni na mikopo)** 2=Commercial Bank (**Benki za kibiashara)**

3=ROSCA (rotating savings and credit assoc) - **Vyama** 4=NGO/MFI (**Mashirika yasio ya kiserikali na yale madogo ya kifedha)**

5= Mwea Rice Growers and Millers Association (Ushirika wa Wakulima na Wasario wa Mchele, Mwea) 6=Relative/friend (**Jamaa/marafiki)**

7=Informal money lender (**Mikopo ya mitaani)** 8=Other specify (Zingine elezea) _______________________

Q9d. How was the credit repaid **(Mkopo ulilipwa vipi)**? _________________________

1=Rice sales **(Mauzo ya mazao ya mchele)** 2=Other crop sales (**Mauzo ya mazao mengine shambani)** 3. Livestock sales (**Mauzo ya mazao ya mifugo)**
4=Off-farm income (**Mazao yasio ya shambani)** 5=Both crop and livestock income (**Mauzo ya mazao ya mifugo na mimea)**

6=Other Specify (Zi**ngine elezea) ______**

Q9e. Are you a member of any group/cooperative that is involved in rice production/marketing (**Je, wewe ni mwanachama wa kikundi/shirika lolote linalohusika na ukulima wa mchele au mauzo yake**? ___________ 1=Yes (Ndio) 2=No(La)

Q9eii. If Q9e is yes, which one (Iwapo jibu la Q9e ni ndio, ni shirika/ kikundi gani)? ________________

1=Producer cooperative (Shirika la Wakulima) 2=Multi-purpose cooperative (Shirika la ujumla) 3=Savings and credit cooperative (Shirika la arbuni na mikopo) 4=Informal/ self-help group 5= Mwea Rice Growers and Millers Association (Ushirika wa Wakulima na Wasario wa Mchele, Mwea)

6=Other specify (Zingine elezea) ___________

Q9f. What services do you obtain from the group or cooperative (Unapata huduma zipi kutoka kwa kikundi hiki au shirika hili)?

0=None (Hakuna) 1=Training (Mafunzo) 2=Marketing (Uuzaji) 3=Input acquisition (Kupata pembejeo)

4=Financial services (Huduma za kifedha) 5=Buying household items (Ununzi wa bidhaa za nyumbani) 6=Other specify (Zingine elezea) ….

10.0 INFRASTRUCTURE MUUNDOMBINU (Distance should be recorded in kilometers-Hatua inapaswa kurekodiwa katika kilomita)

Q 10. Distances from your homestead (Hatua kutoka nyumbani kwako)

a. What is the distance from your homestead to where you buy **farm inputs (**Ni umbali upi kutoka nyumbani hadi unakonunua mahitaji ya shamba)? **FERTKM** ___________

b. What is the distance from your homestead to the nearest **fertiliser seller (**Ni umbali upi kutoka nyumbani hadi unakonunua mbolea)? **FERTSKM** ___________

c. What is the distance from your homestead to where you buy **rice seed** (Ni umbali upi kutoka nyumbani hadi unakonunua mbegu?) **SEEDSKM** ___________

d. What is the distance from your homestead to a **motorable road (**Ni umbali upi kutoka nyumbani hadi barabara ya usafiri)? **DMTROAD** _________

e. What is the distance from your homestead to a **tarmac road (**Ni umbali upi kutoka nyumbani hadi barabara ya lami)? **DTMROAD** _________

f. What is the distance from your homestead to a **matatu/bus stop (**Ni umbali upi kutoka nyumbani hadi pahali pa kuabiria matatu)? **DMSTOP** _________

g. What is the distance from your homestead to the nearest **piped water (**Ni umbali upi kutoka nyumbani hadi pahali palipo na maji ya mfereji? **DPH2O** _________

h. What is the distance from your homestead to the nearest **health centre (**Ni umbali upi kutoka nyumbani hadi zahanati ya karibu)? **DHLTCTR** _________

i. What is the distance from your homestead to the nearest **electricity supply (**Ni umbali upi kutoka nyumbani hadi palipo na stima)? **DELES** __________

j. What is the distance from your homestead to the nearest **mobile services (**Ni umbali upi kutoka nyumbani hadi palipo na huduma za simu ya rununu)? **DMOBS** ___________

k. What is the distance from your homestead to **extension advice (**Ni umbali upi kutoka nyumbani hadi alipo afisa wa kilimo)? **DEXTS** ___________

l. What is the distance from your homestead to the nearest **primary school (**Ni umbali upi kutoka nyumbani hadi shule ya msingi ya karibu)? **DPRISCH** _____________

m. What is the distance from your homestead to the nearest **secondary school (**Ni umbali upi kutoka nyumbani hadi shule ya upili ya karibu? **DSECSCH** _____________

n. What is the distance from your homestead to the nearest market place (Ni umbali upi kutoka nyumbani hadi sokoni)? **DMKT** __________

11.0 Do you face following challenges as a rice processor?

Input costs (Garama ya pembejeo)	**Output price (**Bei ya mazao)	**Infrastructure (**Muundombinu)	**Technology (**Teknolojia)	**Support services (**Hudumu za kimsingi)
High energy costs (Bei za juu zanishati)	Lack of reliable market for rice (Ukosefu wa soko za mchele za kutegemewa)	Insufficient irrigation water (Upungufu wa maji ya kunyunyiziza shambani)	High incidences of pests and diseases (Mkurupuko wa magonjwa na visumbufu)	Poor access to credit (Ukosefu wa huduma za mikopo)
High labour costs (Garama za juu za kazi)	Low output price (Bei ya chini ya mazao)	Poor roads (Barabara mbovu)	Poor soils (Udongo mbovu)	Lack of extension services (Ukosefu wa huduma za afisa wa kilimo)
Others specify (Zingine elezea)	Others specify (Zingine elezea)	Others specify (Zingine elezea)	Others specify (Zingine elezea)	Others specify (Zingine elezea)

1 = Yes 2 = No

Thank you for taking your time to participate in this study.

Appendix Q: Summary budget for field work

Budget Items	**Estimated Cost (AusD)**
A. FIELD SURVEY COSTS	
Cost of field surveys in four rice growing regions of 800 farmers @ 6 dollars per farmer	4800
Cost of field surveys in three rice growing regions of 150 rice millers @ 6 dollars per processor	900
Cost of pretesting 30 questionnaires @ 6 dollars	180
B. TRANSPORTATION COSTS	
Car Hire for field survey	3,000
Fuel for hired car	470
Bus Fare for local travel to meet with various stakeholders	150
C. DATA ENTRY	
Data entry costs	200
C. MISCELLANEOUS	
Meeting facilitation with farmers and other stakeholders	50
Hiring of facilities for meetings	50
Communication costs	100
Stationery and Photocopying	100
TOTAL COSTS	**10,000**

Appendix R: Field work photographs

Rice drying and milling

Rice fields



Enumerators conducting the farmer interviews

Rice millers interview